Automatic Station Issue

THREE DOLLARS PER YEAR

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GENERAL ELECTRIC REVIEW

VOL. XXVIII, No. 6

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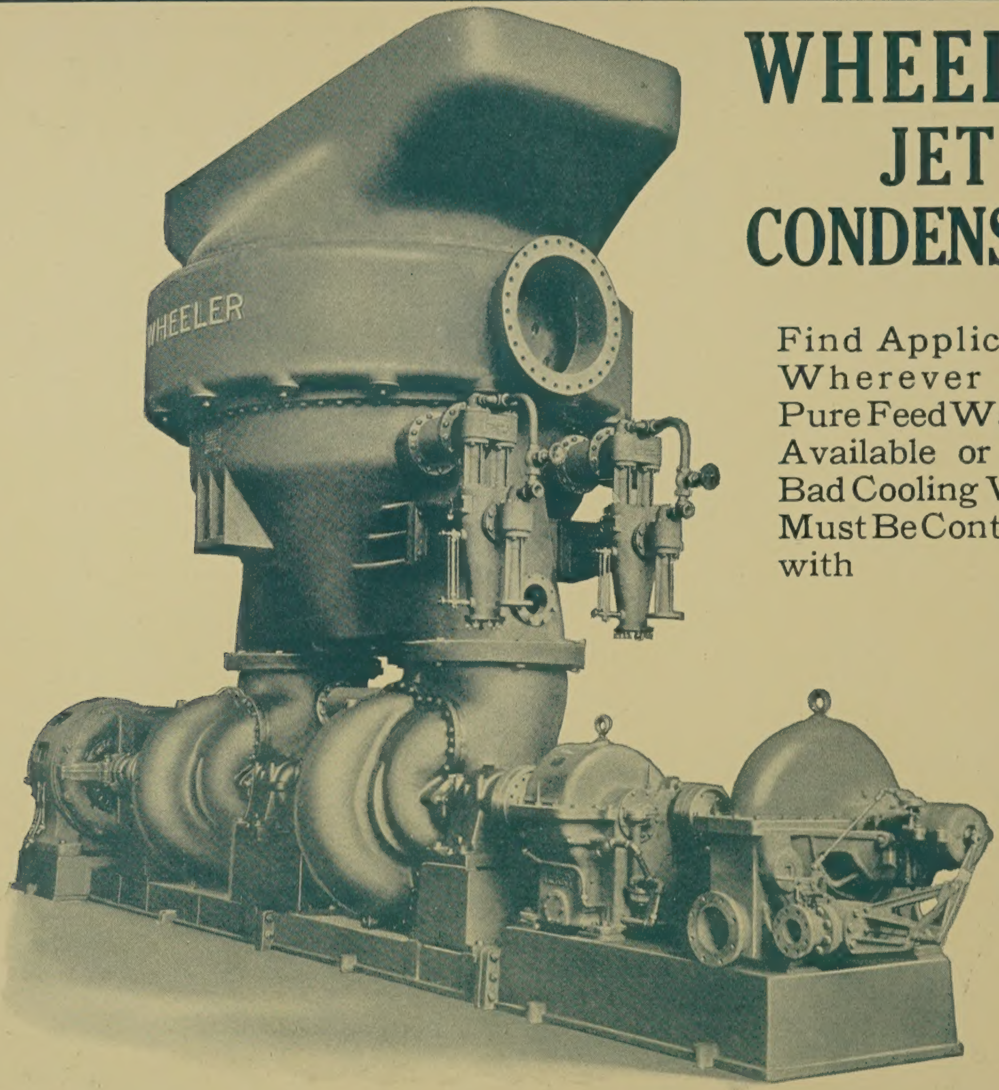
General Electric Company's Publicity Department
Schenectady, N. Y.

JUNE, 1925

FROM WATERPOWER TO HORSEPOWER TO KILOWATTS WITHOUT HUMAN AID

In This Issue:

Electric Service through Automatically Controlled Hydro-electric Units, Synchronous Converters and Condensers, Motor-generator Sets, Transformer Banks and Feeders



WHEELER JET CONDENSERS

Find Application Wherever Soft, Pure Feed Water Is Available or Very Bad Cooling Water Must Be Contended with

WHEELER PRODUCTS INCLUDE

- CONDENSERS - ALL TYPES
- COOLING TOWERS - HEATERS
- STEAM JET AIR PUMPS
- HEAT EXCHANGERS
- EXPANSION JOINTS
- EVAPORATORS
- BOILER FEED PUMPS
- CENTRIFUGAL PUMPS
- TURBINES
- CONDENSER TUBES
- BRASS & COPPER PIPE

THE 15,000-kw. Unit shown above combines the flexibility of a double cone unit with the small space requirements of a single unit. Only 20 ft. head room is needed (16 ft. omitting exhaust connection).

Variable heat balance requirements are met by driving one of the removal pumps with an electric motor and the other with a steam turbine. Duplicate Steam Jet Air Pumps make it possible to save steam under warm water conditions.

Write for Catalog G-112.

WHEELER CONDENSER & ENGINEERING CO.
149 Broadway, New York
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OUTPOSTS OF SUPER-POWER

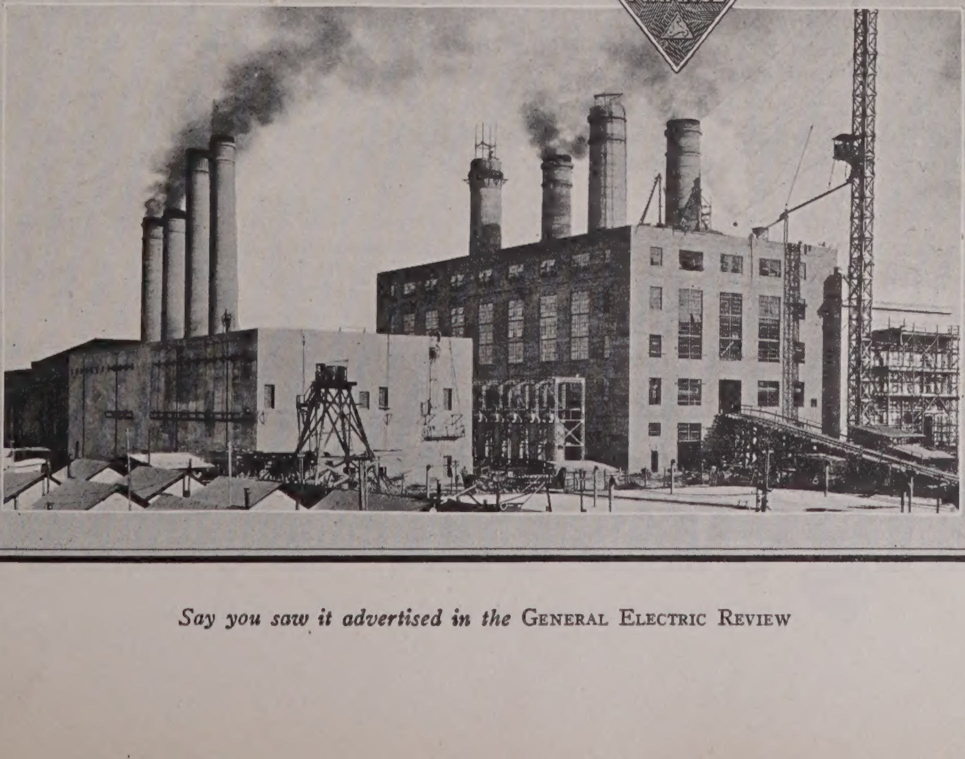
AT the left is the new Weymouth Station of the Boston Edison Company.

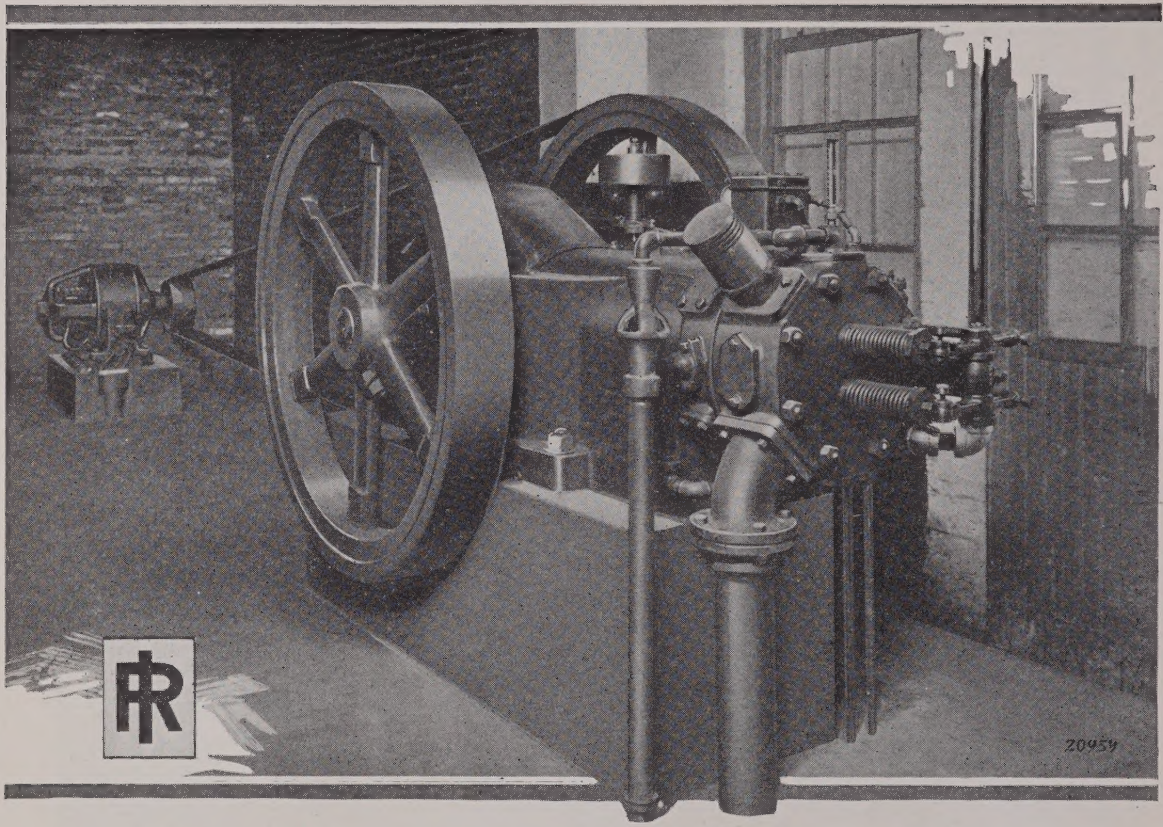
Below is the new Long Beach Station of the Southern California Edison Company of Los Angeles.

With the completion of these stations — outposts of super-power serving 3,000,000 people — the power construction work of Stone & Webster, Inc., throughout the country exceeds 2,250,000 horse power.

STONE & WEBSTER
INCORPORATED

DESIGN-BUILD
OPERATE
FINANCE





I-R Direct Injection Oil Engines

50—100—150 B.H.P. SIZES

The Ingersoll-Rand Type "PO" is a small oil engine operating with full Diesel economy at any load. It burns any fuel oil that can be used in any other Diesel engine. It burns all of the oil injected into the cylinder—thus insuring high over-all efficiency.

No pulling of pistons, no scraping of valves, no needless wear.

The illustration shows an Ingersoll-Rand Type "PO" 50 B.H.P. oil engine driving a direct-current generator at the Burlington County Hospital, Lisben, New Jersey.

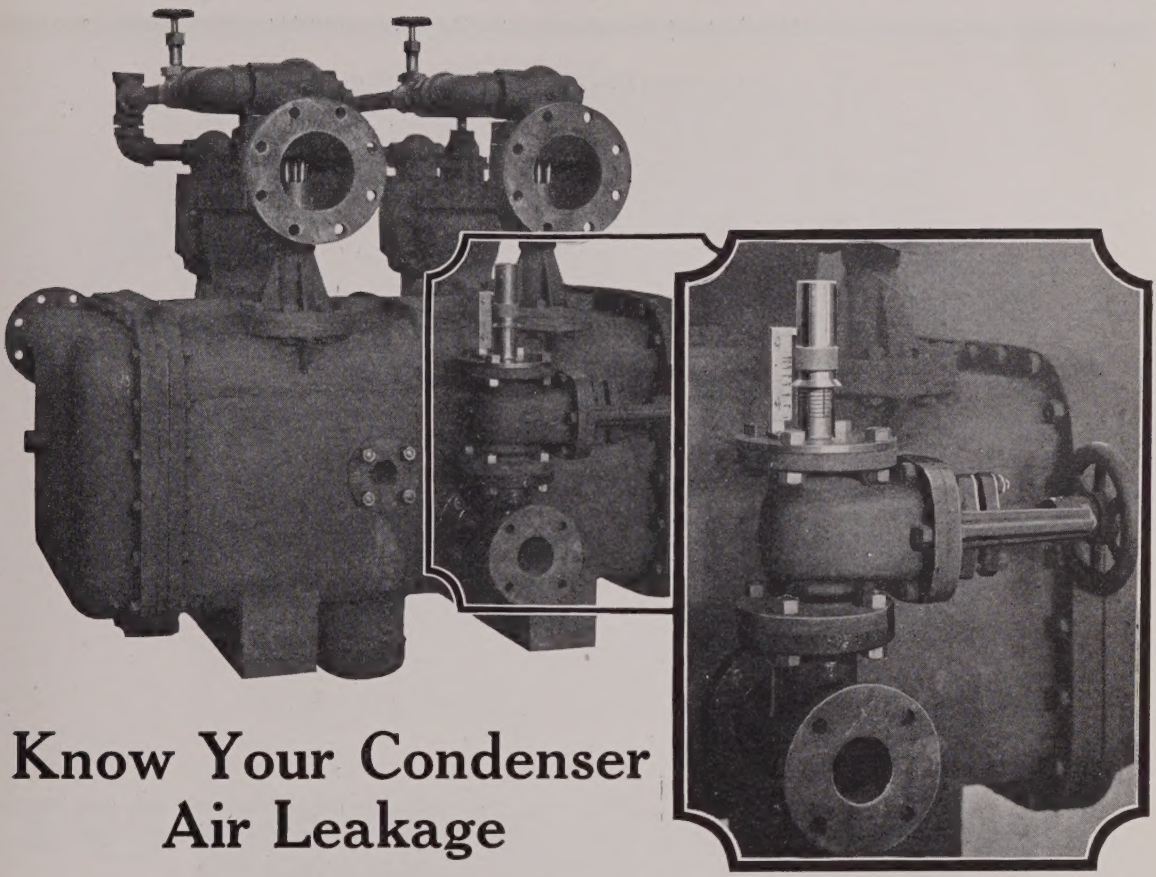
This is another installation where Ingersoll-Rand oil engines are cutting power costs in driving pumps, generator, compressors and line shafts.

Let our engineers show you how these simple, rugged engines will reduce *your* power costs.

INGERSOLL-RAND COMPANY—11 BROADWAY, NEW YORK CITY
Offices in principal cities the world over
FOR CANADA REFER—CANADIAN INGERSOLL-RAND CO., LIMITED, 260 ST. JAMES STREET, MONTREAL, QUEBEC.

Ingersoll-Rand

Say you saw it advertised in the General Electric Review



Know Your Condenser Air Leakage

It is extremely important in the operation of surface condensers to be able to check air leakage into the condenser. Until recently such checking was difficult and inconvenient.

The Elliott-Ehrhart Air Leakage Meter illustrated above, when installed on an ejector which employs a surface after-condenser for condensing the ejector steam, will show immediately any abnormal air leakage. The meter is accurate, extremely simple, and sturdy. The gliding cylinder or air bell rises in proportion to the air leakage and its flanged edge indicates on a scale the air leakage in cubic feet per minute.

The Air Leakage Meter is described in our Air Ejector Bulletin C-2. An article in the December, 1924 issue of our bi-monthly magazine "Powerfax,"* further described its use. Ask for these publications.

*If you are not receiving Powerfax and would like to be on the mailing list, write us.

ELLIOTT EHRHART Air Leakage Meter

ELLIOTT COMPANY

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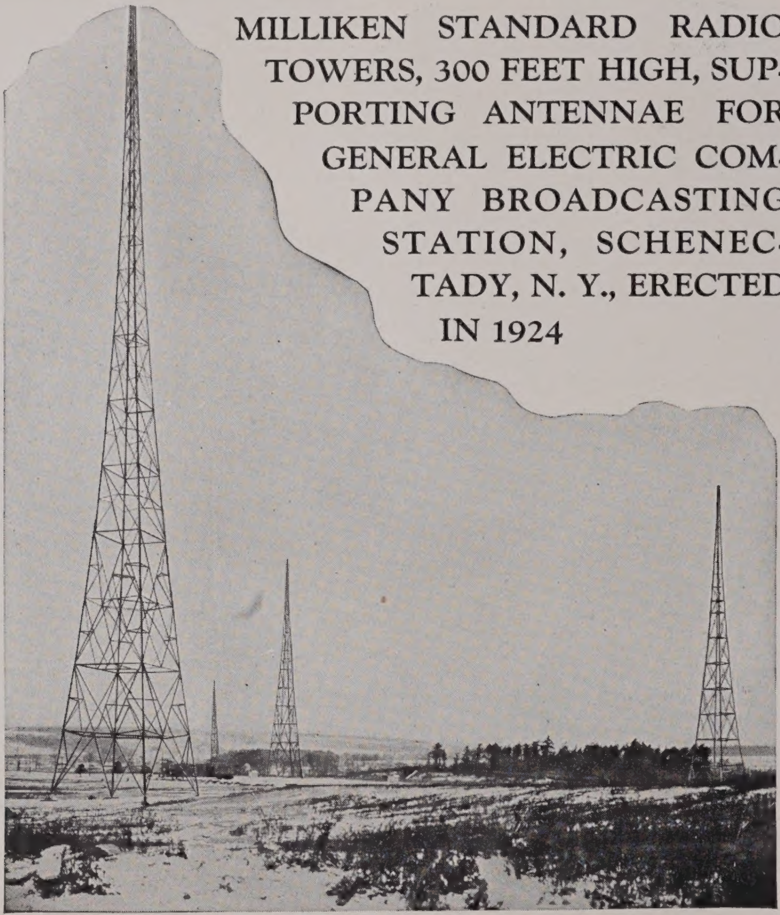
C-270



MILLIKEN STANDARD RADIO TOWERS, 300 FEET HIGH, SUPPORTING ANTENNAE FOR GENERAL ELECTRIC COMPANY BROADCASTING STATION, SCHENECTADY, N. Y., ERECTED IN 1924

MILLIKEN Standard Radio Towers, 300 feet high, are being used by the General Electric Company at its new experimental broadcasting station, Schenectady. These towers were selected by the leading broadcasting station in the world for stability, reliability, long life and economy, to secure the best results in long distance service.

The General Electric Company leads in all electrical development and specialized broadcasting equipment. This station represents the last word in experimental broadcasting.

MILLIKEN Standard Radio Towers are hot galvanized throughout. They are carried in stock for immediate shipment and are furnished in heights ranging from 66 feet to 300 feet.

Milliken towers are used also at such important broadcasting stations as—

WPG —Municipal Station, Atlantic City, N. J.
WEAF—American Telephone and Telegraph Co., New York
WSAI —United States Playing Card Co., Cincinnati
WEEI —Edison Electric Illuminating Co., Boston
WBZ —Westinghouse Electric & Mfg. Co., Springfield, Mass.
WHAZ —Rensselaer Polytechnic Institute, Troy, N. Y.
WMAF—Round Hills Radio Corporation, Dartmouth, Mass.
WCX —Detroit Edison Co., Detroit
WGBS —Gimbel Brothers, New York
WAHG—A. H. Grebe Co., Brooklyn, N. Y.

Catalogs in English and Spanish will be furnished on request.

MILLIKEN BROTHERS MFG. CO., Inc.

2341 Woolworth Building - - - - New York, N. Y.

Also, Manufacturers of Transmission Towers and MILLIKEN BUILDINGS

The Connors Creek Station of The Detroit Edison Company is equipped with 49,922 condenser tubes made by The American Brass Company.

195 Miles in One Station

The Connors Creek plant of The Detroit Edison Company is equipped with 195 miles of condenser tubes supplied by The American Brass Company.

These condenser tubes, serving an aggregate turbine capacity of 180,000 k.w., were selected because of The American Brass Company's reputation for producing tubes of uniform and dependable quality.

Write for booklet: "Anaconda Condenser Tubes," an authoritative discussion with recommended specifications.

THE AMERICAN BRASS COMPANY

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A Cute Little Devil

TO the uninitiated, a sparking commutator may be "pretty" and "cute" but to the electrical man it means poor commutation and actual destruction of parts.

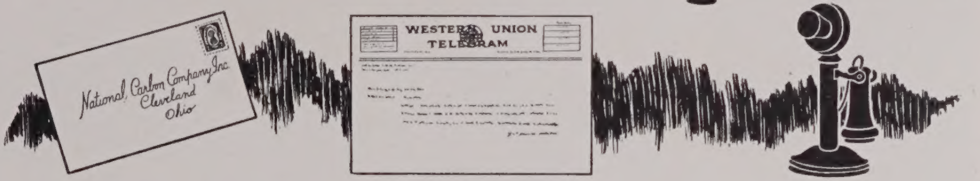
STACKPOLE Brushes eliminate trouble, —they function smoothly and efficiently in any service and assure cool operation and perfect commutation with minimum commutator wear.

Stackpole's catalogue gives interesting and instructive data on Carbon Brushes for every service.

Stackpole carbon brushes

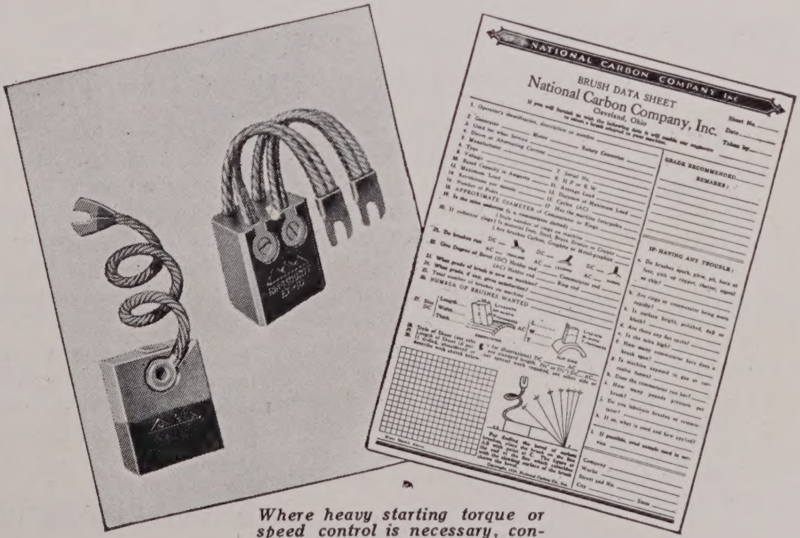
STACKPOLE CARBON CO.
ST. MARYS ~ PA.

write – wire – phone



WHEN you need brushes on short notice for any reason *write, wire* or *phone* the nearest of our four plants, and the National Pyramid Brushes you need will be on their way to you immediately.

Have we complete data sheets on your motors, generators and converters? Information regarding our data sheet service gladly sent on request.


NATIONAL CARBON COMPANY INC

BRUSH DATA SHEET

National Carbon Company, Inc.

Cleveland, Ohio

Where heavy starting torque or speed control is necessary, consider the advantages of Commutator Type Motors.

The services of our Sales Engineers are always at your disposal

Manufactured and guaranteed by

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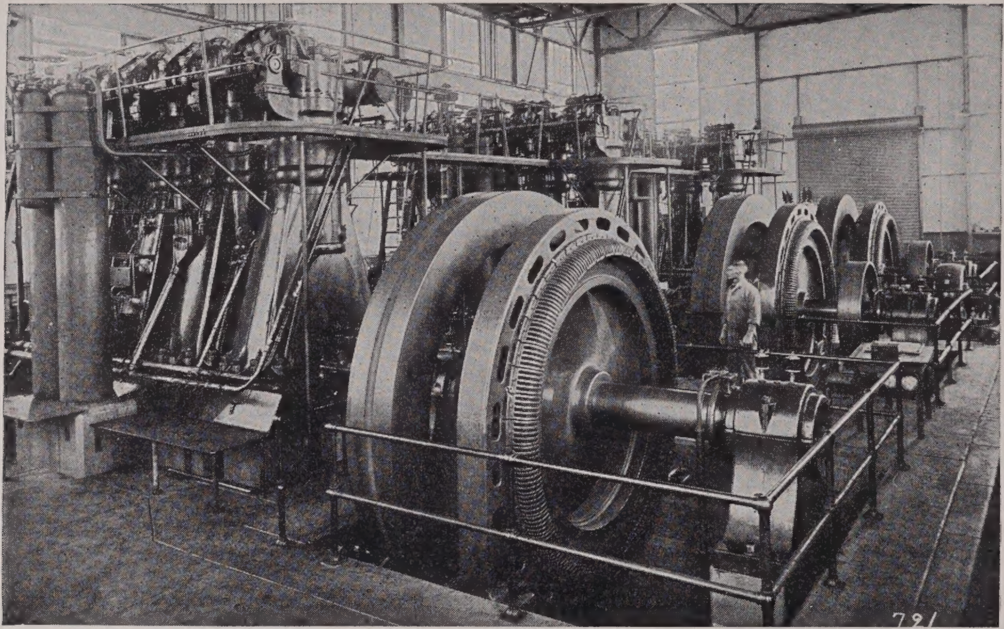

Three 500-b.h.p. McIntosh & Seymour Diesel Engines driving 437-kv-a. generators in substation of a large central Texas power company

How progressive central stations can make far-away business profitable

POWER companies desiring to build up business economically in outlying districts not yet reached by their lines can do so with temporary local installations of McIntosh & Seymour Diesel-Engine-driven generators. These will operate very efficiently while enough load is being built up to justify extension of the lines from the main station, and then the Diesel outfits, being self-contained, can readily be moved to another location and the process repeated—or the Diesel outfits may be left to feed into the combined system with equally high efficiency.

The installation shown was made with this intention and in about two years connection with the main transmission lines was warranted. The Diesel Outfits proved very satisfactory and instead of being moved have for several years more fed into the connected lines and operated with a load factor of 90 per cent.

Large companies who want additional power at a distance or seek better facilities for handling the peak loads will find Diesel Engines a most logical solution.

Our Engineers will assist in determining desirable arrangements and are prepared to offer attractive guarantees.

Ask for our literature and tell us your needs.

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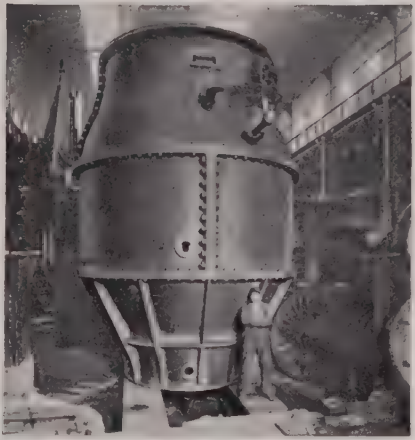
Designers and Builders of

JOHNSON HYDRAULIC VALVES

Six of these valves installed in penstocks supplying 12,000 h.p. hydro electric units. Two 42-in. valves of same type for exciter units. First installation made in 1910.



Nine-foot vertical JOHNSON HYDRAULIC VALVE in one of the prominent Power Plants at Niagara Falls

Valves in continuous service since installation without repairs or spare parts of any description.

Operating record perfect.

Performed Notable Service in Emergency

A serious break below the JOHNSON VALVE caused a flood of water in power house which threatened complete and indefinite shut down of the entire station. Prompt, reliable and quick closure of the JOHNSON VALVE limited the flood to a duration of FOUR MINUTES. Valve closure required only ONE MINUTE, the first three minutes used to notify operator in valve chamber above power house. AUTOMATIC CLOSING DEVICE would have limited flood to less than one minute, but this feature was not available when valve was installed. RELIABLE CLOSURE of valve saved 10 generators (110,000 h.p.) from flood and prevented incalculable loss in damage to apparatus and loss of power to consumers.

Penstock below valve BONE DRY during shut down as no water whatsover leaked through Johnson Valve seat.

Closure performed in emergency and in regular service with characteristic damping of plunger stroke just before reaching seat.

WRITE FOR JOHNSON VALVE BULLETIN NO. 3

Associated Companies

THE PELTON WATER WHEEL CO., San Francisco and New York
DOMINION ENGINEERING WORKS, LTD., Montreal, Canadian Licensees
SOCIEDADE ANONYMA, HILPERT, Rio de Janeiro, Brazilian Licensees

CONTINUED RECOGNITION

AGAIN the U. G. I. Contracting Company has asserted the fact that it is recognized among the leading electrical engineering forces in the country, competent to undertake the most complicated of engineering problems. This is evidenced by the award to it of the contract to design and construct the new power plant for the Comal Power Company, near San Antonio, Texas.

Many of the leading engineering firms in the country competed for this most important power contract which involves several original engineering problems.

THE U·G·I·CONTRACTING COMPANY

Philadelphia, U. S. A.

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BUILDERS OF

Industrial Plants *Steam Power Plants* *Hydro Developments* *Gas Plants* *Public Works*

"A Valuable Help in Designing Ball Bearing Motors"

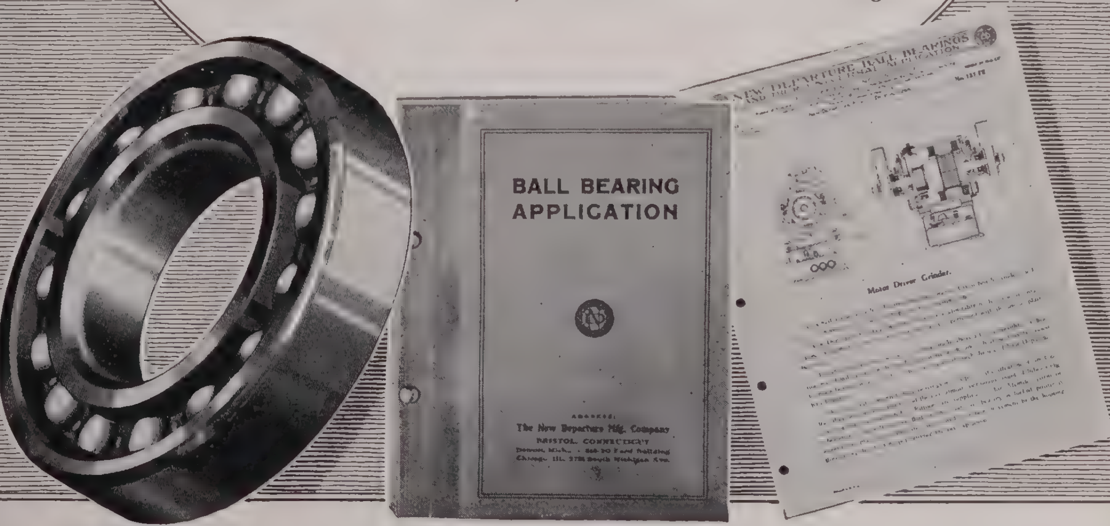
There is good reason for the lively interest in the use of ball bearings in electric motors, by users, distributors and manufacturers alike.

How the New Departure Ball Bearing Reference Book can help you keep abreast of developments in this field can be judged by the following outline of its contents:

Complete catalog description and illustrations; dimensional tables; general mounting; clamping and retaining methods; limit tolerances; closures; calculation of bearing loads due to gears and other conditions; recommended sizes for horizontal electric motors, and bulletins showing application data for various types of machines employing integral motors, etc., etc. New data issued monthly.

Furnished in loose-leaf binder without obligation to those who are in a position to use it to advantage.

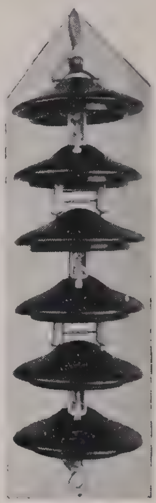
THE NEW DEPARTURE MANUFACTURING COMPANY
Detroit Bristol, Connecticut Chicago



New Departure Ball Bearings

185

The Ohio River Edison Company completes the First installation of the NEW LOCKE HEWLETT insulators



To Stevens & Wood, Inc., New York, goes the credit for the first installation of the New Locke Hewlett insulators. Quick to realize the importance of so valuable a development, the Stevens & Wood engineers ordered comparative tests made with other types. Every known method for determining ultimate performance under operating conditions was employed under the direction of research engineers in the foremost electrical laboratory of the country. The electrical and mechanical characteristics far exceeded the values ever before developed in a Hewlett insulator, and the decision was made to install the New Locke Hewletts on the new line of the Ohio River Edison Company, then under construction.

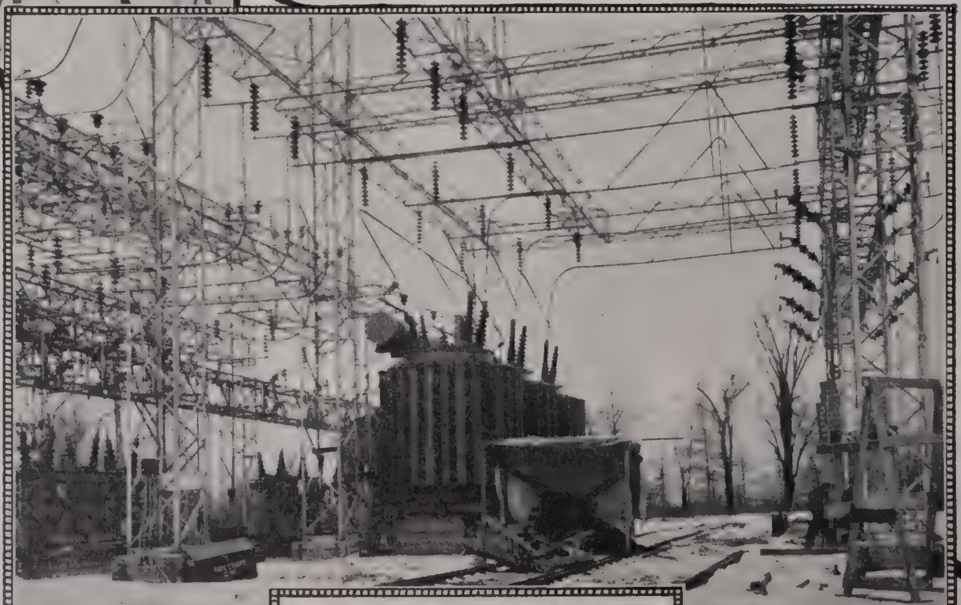
STEVENS & WOOD Inc.
DESIGN
FINANCE
CONSTRUCT
MANAGE
ENGINEERS

This is a 132,000-volt line, forty miles in length, extending from the generating station at Toronto, Ohio, to the Boardman Substation four miles south of Youngstown. At this point the energy is stepped down to 66,000 volts and is connected with the properties of the Pennsylvania-Ohio Electric Power and Light Company, the Pennsylvania-Ohio Electric Company, the Shenango Valley Electric Company and other subsidiaries of the Republic Railway and Light group.

The New Locke Hewletts are also employed in suspension at Toronto and Boardman for all main busses and taps. This line is now in operation, and operating companies are referred to Stevens & Wood for information covering the results so far obtained.

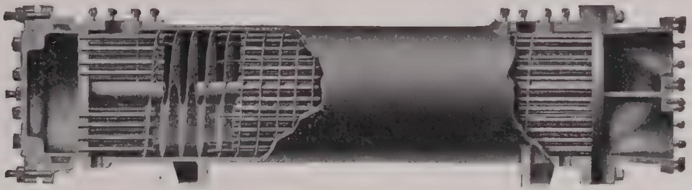
LOCKE INSULATOR CORPORATION

BALTIMORE, MARYLAND *Factories at Victor, N. Y. and Baltimore, Md.*



LOCKE
PORCELAIN

Prevents overheated turbine bearings



The G-R Multiwhirl Cooler keeps turbine bearing and reduction gear oil at the temperature for proper lubricating effect. A safeguard against overheated bearings and a help to greater oil economy. Over 2000 in use.

Send for Bulletin 904

The Griscom-Russell Company
2140 West Street Building, New York

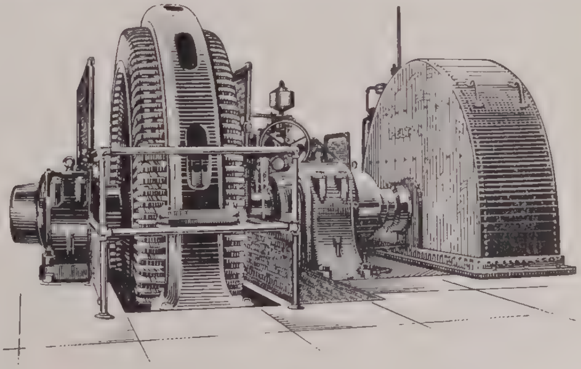
MULTI-WHIRL COOLERS

PELTON

Simplicity—
—Reliability

Where hydraulic and other conditions permit the installation of impulse turbines, this type of unit offers many advantages. The simplicity of the water wheel means lower first costs, easier and quicker renewal of parts and, due to the lesser number of moving elements and absence of close clearances shutdowns resulting from ordinary causes are eliminated.

Ask for our bulletin No. 19, descriptive of Pelton water wheels and accessories.



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Hydraulic Engineers
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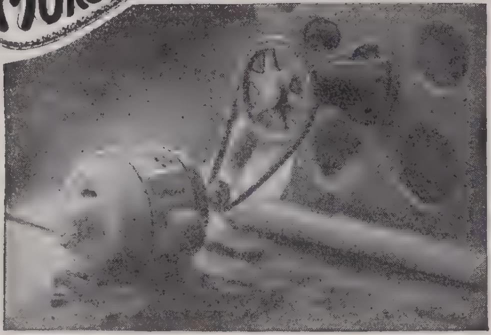
100 Broadway, New York, N. Y.
Divisional Office in American Trust Building, Birmingham, Ala.

Associated Companies: Wm. Cramp & Sons Ship & Engine Bldg. Co., Philadelphia; Dominion Eng. Works, Montreal; Sociedade Anonyma Hilpert, Rio de Janeiro.

Pacific Coast Representatives: The M. W. Kellogg Co., Jersey City, N. J.; Larner Engineering Co., Philadelphia, Pa.; De La Vergne Machine Co., New York, N. Y.

PELTON

MORSE SILENT CHAIN DRIVES



3-H.P. Morse Silent Chain driving from motor to band scroll saw.

For short center drives

Morse Silent Chain Drives can be used over long or short center distances, as best suits the arrangement of machinery. For this reason they are indispensable in many plants where machines are provided with built-in motors or driven by individual motors.

Morse Drives permit any desired speed reduction in a single drive, do not involve delicate adjustments in alignment of motor to machine shaft, run quiet without chattering, do not slip, are flexible enough to absorb shocks or jars, and at all times transmits 98.6% of the developed motor horsepower.

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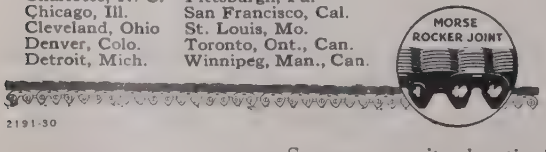
There is a Morse Engineer near you



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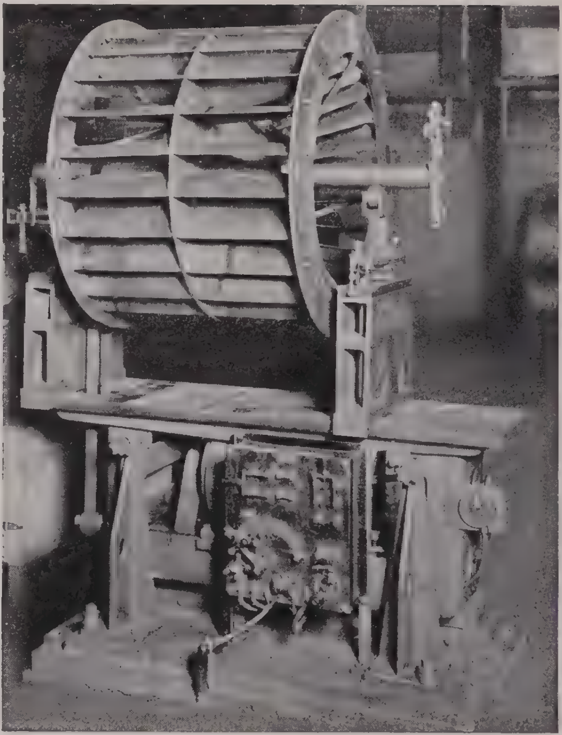


Balance—

NOTHING essential to the successful operation of a stoker fan is more important than a perfect running balance. A static balance (much more easily obtained) will often permit the wheel to run out of true at high speeds; with a resulting vibration just as serious as if the wheel were out of balance statically.

For this reason, all Buffalo stoker fan wheels are given a running balance on a dynamic balancing machine, insuring a perfect running balance.

We take extreme pains in the manufacture of all parts of Buffalo equipment to secure the same satisfactory results.

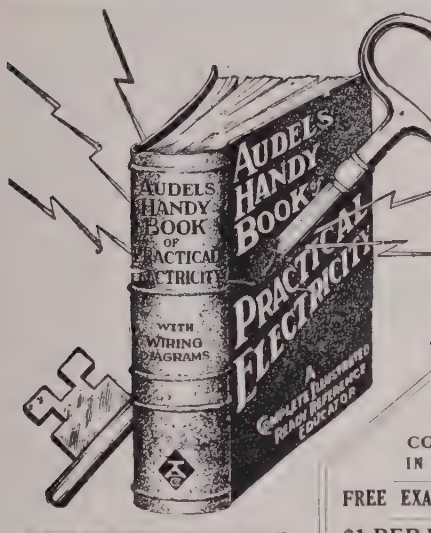
That's why so many large power companies are using

"Buffalo" *Mechanical Draft Apparatus*

We have an interesting new catalog No. 730 that tells more about it. Send for your copy now.

Buffalo Forge Company

170 Mortimer Street Buffalo, N. Y.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Here is an up-to-date, quick Ready Reference. It gives complete instruction and inside information on every electrical subject. Every point clearly explained in plain language and diagrams that are easily understood. Handy to use. Easy to learn from. Subjects arranged in progressive manner for the student and with complete index which gives information instantly to professional workers. A time saver, money saver, and a helping hand for Engineers, Professional Electricians, Students and all interested in electrical work.

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Audels Handy Book is a magnificent volume that you will be proud to own and carry with you. Gilt Edged. Durable real leather binding. 1040 pages of strong white paper. Large Type. 2600 illustrations and diagrams. A mine of information and a most unusual value at only $4. *Send no money.* Pay nothing to postman.

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KEYSTONE GREASE

Why slave over bearings?

MINUTES lost are dollars wasted where workmen must go from one bearing to the other, lubricating every one individually.

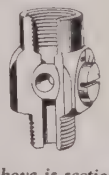
Such waste does not end here. It is not surprising that bearings difficult of access, hazardous to reach, should be neglected. Friction, wear, faulty operation and eventual breakdown of moving parts are the inevitable consequences of such neglect.

It is all so unnecessary.

With the KEYSTONE SAFETY SYSTEM OF KEYSTONE GREASE LUBRICATION, the operator stands at one central, safe, convenient place and, turning a wheel, lubricates every bearing on the machine. The grease is distributed by pressure through ordinary piping to the bearings, each of which receives its proper share of grease through adjustable reduction valves. Write for details —Free literature!

KEYSTONE LUBRICATING CO.
Est. 1884
PHILADELPHIA, PA.
at 21st and Clearfield Streets

Sectional view below of lubricator, which is the main grease reservoir and agency of compression.



Above is sectional view of Pressure Reduction Valve placed at each bearing.

Keystone Safety System of Keystone Grease Lubrication

B T-H **Electrical Equipment**

Steam Turbines
Turbo-Generators
Turbo-Alternators
Power Station Switchgear
Rotary Converters
Sub-Station Switchgear
Industrial Motors
Industrial Switchgear
Electric Locomotives

This Company manufactures electrical equipment for every service, ranging from the smallest lamp to the largest electrical machinery manufactured in the United Kingdom.

The British Thomson-Houston Co., Ltd.
Electrical Engineers and Manufacturers
Head Office: Rugby, England London Office: "Crown House," Aldwych

---

Investment Bankers
are offered
Power and Light Securities

issued by companies with long records of substantial earnings.

We extend the facilities of our organization to those desiring detailed information or reports on any of the companies with which we are identified.

Electric Bond and Share Company
(Paid-up Capital and Surplus $70,000,000)
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GENERAL ELECTRIC REVIEW

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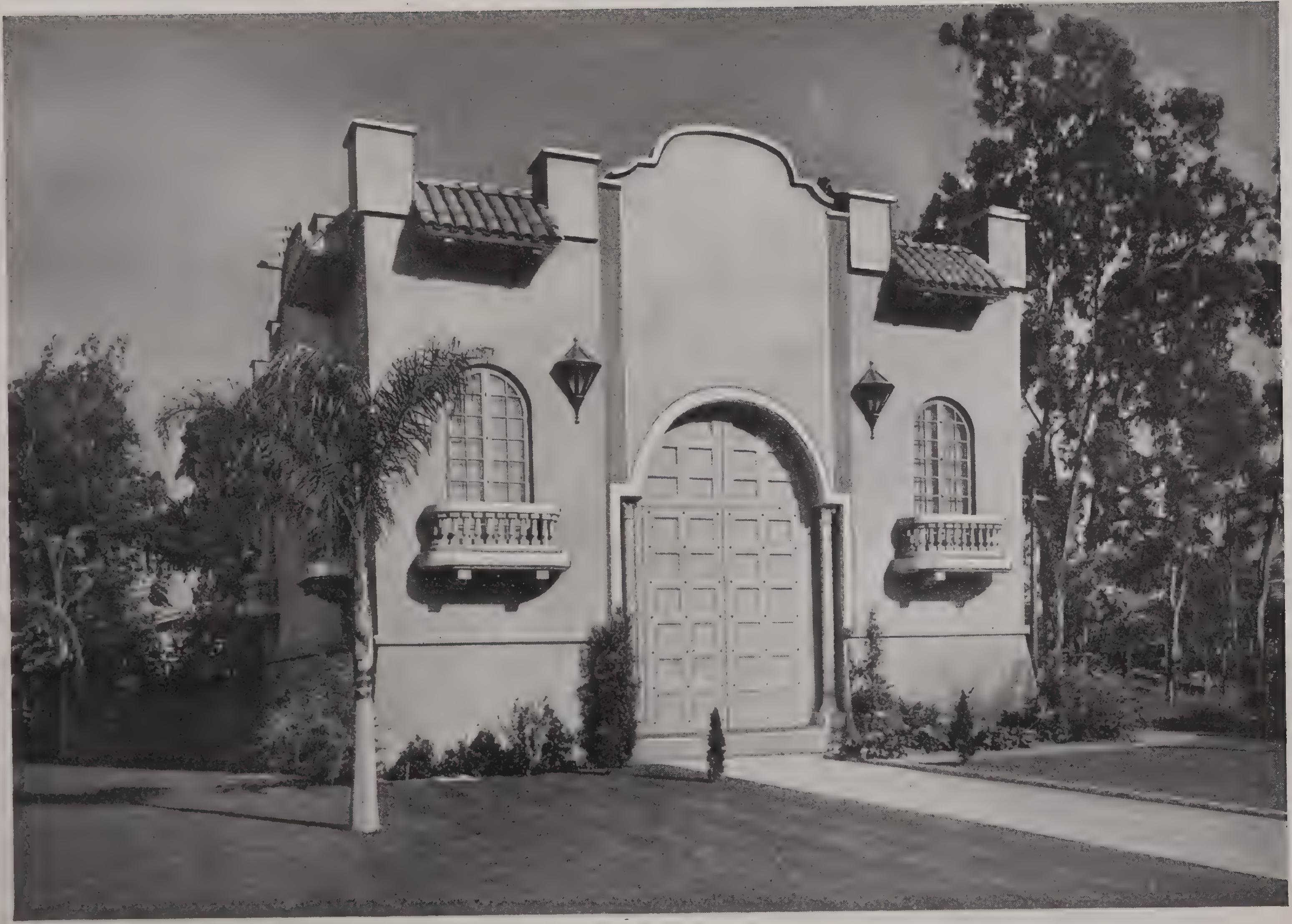


SQUNDPROOF CONSTRUCTION AND ARCHITECTURAL BEAUTY MAKE THE AUTOMATIC SUBSTATION A WELCOME MEMBER OF THE FINEST COMMUNITIES

Few Los Angeles residents realize that this quiet and unobtrusive building in their midst is furnishing them with the service of 2700 horse power

GENERAL ELECTRIC REVIEW

DIGEST OF WHAT OUR AUTHORS HAVE TO SAY OF AUTOMATIC OPERATION

"Quickness of mind, eye, and hand of the operator has ceased to be the requirement it once was, for the safety of electrical equipment is becoming less and less dependent on these attributes of man. Knowing what the ideal operator would do, it is but a step to substitute an automatic machine to take his place." This simple statement of today's situation, as expressed by Mr. Spease, is further developed by Mr. Place who says "there now remains only the forming of a decision as to the particular interpretation of conditions to govern the operation, the taking of precautions so as to avoid trouble, and then the making sure that the advantages to be gained are worth the expense of doing what is contemplated."

One of the many advantages which have been found to be "worth the expense" is cited as follows by Mr. Johnson, of the Chicago, Aurora & Elgin R. R.: "The astonishing feature of these automatically controlled converters is their ability to move heavy trains whose demand is far in excess of the capacity of the substation." Another advantage is "the rapidity with which service can be resumed after a shutdown," according to Mr. Baker. Speaking for the Chicago, North Shore & Milwaukee R. R., Mr. Jones makes the statement that "automatic equipments can be absolutely depended upon to render service equal to if not better than manual equipment" and that his Company now gives "practically no consideration to manual stations when installing additional stations."

In hydro-electric installations, Mr. Place states that the use of automatic control "permits the development and handling of possible sites in a way that will allow the maximum degree of development."

In the central station industry, Mr. Bettis, of the Kansas City Power and Light Co., tells us the application of the automatic substation "has unquestionably been brought about by the demand for better service on the part of the customer and for improved economy and reliability of operation on the part of the public utility company." In this field Mr. Spease remarks that more and more use is being made "of the automatic reclosing feeder, and this type of feeder has in turn proved to be reliable and has given satisfaction wherever used."

"Considerable interest has been manifested by engineers associated with industrial plants in the possibilities offered by the automatic operation of motor-generator and synchronous-converter substations" according to Mr. von Sothen.

"The ability of such a station to reduce the cost of mining" is noted by Mr. Hough as being "one of the major reasons for the increasing interest in automatic substations in this industry. Another definite reason for increasing interest is the realization of freedom from labor trouble, both direct and indirect."

Where it is desired to use supervisory systems in conjunction with automatic equipment, Mr. Stewart claims that these systems of remote control "are of untold benefit to electrical operating companies."

In making a review of the New England district, Mr. Barry observes: "Both industries and central stations are looking to the automatic substation to help solve their problem of better service at lower cost of operation."

Performance

The favorable statements made by the authors concerning the general performance of their automatic equipment are so many as to preclude quoting more than a few here. Mr. Hardaway says the Harrison Substation of the Public Service Company of Colorado "has never failed to operate satisfactorily;" and Mr. Pollard states in the course of describing the Miller Street Substation of the Public Service Electric & Gas Company of New Jersey: "The operation of the automatic equipment has been entirely satisfactory." On the Oregon Electric, "great improvement was immediately noticed in the operating conditions of the synchronous converters after the automatic control was installed" according to Messrs. Cunningham and Barker who conclude: "In brief, automatic operation has proved an unqualified success." Mr. Johnson, of the Chicago, Aurora & Elgin R. R., relates the fact that "the favorable results obtained from the operation of this automatic substation [the first on the road] were a deciding factor in determining the type of equipment to install later. Two more automatic substations were installed * * * * * June, 1923."

Quick starting and availability for load demand are claimed for the automatic hydroelectric station by Mr. Place who cites in confirmation "17½ sec. for 2250-kv-a. units." An outstanding example of performance in a different character of service is offered by the reclosing substation at Medford, Mass., which "was placed in service a short time before one of the worst ice and sleet storms which New England has ever experienced. Even under these exceptionally severe conditions," Mr. Barry says, "the operation of the reclosing equipment was 100 per cent." Another remark on the operation of reclosing equipment comes from Mr. Hardaway: "It is evident from the rapid increase in the use of automatic reclosing equipment by this company [The Public Service Company of Colorado] that the service rendered by the equipment has proved to be entirely satisfactory."

"Reliability of service was another prime factor of consideration in deciding upon the use of automatic equipment," for the Kansas City Power and Light Co., is a pertinent reason offered by Mr. Bettis. Concerning two automatic substations on the Chicago, Aurora & Elgin R. R., Mr. Johnson advances the following figures.: "Since they were installed they have started up and shut down over 5857 times," and "the percentage of perfect operation amounts to 99.18." "In the early years of automatic operation," Mr. Jones says that on the Chicago, North Shore & Milwaukee R.R., "there were a number of control equipment failures, which averaged about one failure per 1000 operations, but as improvements have been made in the equipment these failures have been reduced until today they are almost negligible."

Cost

In the matter of cost, Mr. McCrea asserts that "One company which uses automatic control extensively claims that the total cost of its automatically controlled substations is actually less than if hand-operated stations had been used." The Oregon Electric has but one manually operated substation, and Messrs. Cunningham and Barker say "it costs more to operate and maintain this one manually operated substation than it does to maintain and operate all of the seven automatic substations." In actual figures, these authors credit automatic operation as being responsible for reducing the operating and maintenance cost "from $43,837.54 per year to $10,604.70" to which they add "a further saving of about $3000 per year on power" making "a total saving on operation and maintenance of $5180 per station." Mr. Baker figures that for a typical 600-volt 500-kw. railway substation the "per cent saving [secured by automatic equipment] based on the additional cost of automatic equipment amounts to 31."

For the direct-current substations of the Kansas City Power & Light Co., Mr. Bettis reports "the net saving in operating labor which was secured by using automatic equipment in place of manual equipment was approximately $20,000 per year." In the matter of investment, "the Public Service Company of Colorado has found that the first cost of automatic reclosing equipment is not materially greater than that of manual equipment after adding to the latter the cost of the necessary additional building space, heating equipment, and conveniences for operators," says Mr. Hardaway, who then reports "a net annual saving of approximately $4500 per substation."

In the mining industry, Mr. Hough cites the case of an operating company whose "investment for the automatic equipment was in the neighborhood of $4000 (installed) for a 150-kw. machine" and "reported a saving of $160 a month" at which rate "a yearly saving of $1920 will pay the entire cost of the automatic in about two years." Messrs. Furr and Webb, of the Appalachian Power Company, provide the following handy cost ratio: "To determine the amount which can be economically spent for re-equipping a substation, the saving in operating cost is capitalized at 15 per cent. In other words, the cost of operating a manually operated station less the cost of inspecting an automatic station divided by 0.15 is the amount that the Company can invest for automatic equipment."

Maintenance

On the subject of maintenance, Mr. Jones furnishes the following information concerning the North Shore Road: "There has been only a very small amount of automatic control equipment either repaired or replaced, even in the stations where we have had over 75,000 operations." From experience with the substations of the Kansas City Power & Light Co., Mr. Bettis states that "highly trained maintenance men to take care of the inspections, cleaning, and repairing of the apparatus cannot be dispensed with, however, although very few maintenance men are needed to care for automatic installations as compared with the number required to operate manual installations." The guiding rule of conduct in maintaining automatic stations is well expressed by Messrs. Cunningham and Barker: "It is an excellent plan to pay substation maintainers on the same basis as the Chinese pay their doctors—for keeping them well."

Inspection

The "keeping them well," is a simple matter if proper attention is given to their inspection. "For successful operation of automatic equipment it is necessary to have regular inspections made by a competent inspector." Messrs. Furr and Webb, of the Appalachian Power Company, practice what they preach, for "a competent man is employed as an inspector" who gives "each station a regular inspection once each week." On the C. A. & E. R. R., with which Mr. Johnson is connected, the regular inspection of substations "is conducted weekly by two men;" while on the C. N. S. & M. R. R., with which Mr. Jones is associated, "A regular inspection program has been followed out on all of these stations daily."

Protection

All machinery should be adequately protected. "The automatic station," says Mr. McCrea, "is provided with protective devices not usually found in manually controlled stations, and which do not depend on the watchfulness of an operator." In the Miller Street automatic station of which Mr. Pollard writes, the transformer banks are provided with equipment for protecting them against five contingencies and the motor-generator sets against twelve. Mr. Baker says the typical automatic railway substation is protected against: "Direct-current overload; alternating-current overload; reverse current; low alternating-current voltage; incorrect polarity; overspeed; damage due to flashover or grounds in machine; excessive machine temperatures; excessive bearing temperatures; excessive heating of load-limiting resistance; wrong position of brushes; loss of field; single or reverse-phase starting; single or unbalanced-phase running; and incomplete start."

Noise

The possibilities of silent operation are referred to by Mr. Baker in the following statement: "It is quite evident from several successful special applications that automatic substations may be employed to accomplish results otherwise uneconomical or impracticable, of which the noiseless substation is an outstanding example." Two such substations of the Kansas City Power & Light Co. Mr. Bettis describes as being "located in the basements of 15-story office buildings; also, one in a local club and one in a retail store building. Another is in the basement of a 5-story office building. There has been no objection made by any tenants, owners, or operators of these buildings." Of the Miller Street station of the Public Service Electric & Gas Co. of N. J., Mr. Pollard remarks: "The substation has been in service since the spring of 1924, and it is impossible for persons outside the building to detect any noise or vibration caused by the apparatus."

Devices

With regard to automatic control equipment, Mr. Brockway introduces his article with the statement: "The successful operation of an automatic switching installation depends not only upon the correctness of the scheme of control but also upon the proper functioning of the devices which form the equipment. A perfect plan of connections is of no avail if the devices cannot be relied upon." He concludes with the remark that the use of "fully tested and standardized devices has been shown by long experience to result in thoroughly dependable automatic switching operation with the minimum expenditure of time and money to maintain continuously a very high grade of service."

Installations

Because the real test of the worth of an idea is the extent to which it has found application, the following figures from Mr. Ewald's article are convincing proof of the value of automatic control. Following the first automatic installation made about a decade ago, the number of such equipments purchased from the author's company has averaged two every three days, amounting at the present time to 2459. These render 2,217,727 kw. automatically serviceable and are divided as follows: 569 equipments for controlling 493,180 kw. in motor-generator sets, synchronous converters and condensers, ranging in size from a 25-kw. lighting motor-generator set to a 9375-kv-a. hydro-electric unit; and 1890 feeder, supervisory, and power line switching equipments for directing the flow of 1,724,547 kw. The early growth in the application of automatic operation was partially checked by more urgent wartime activities but "since 1919 the business has increased rapidly; the value for 1924 being about 15 times that of 1919."

Future

As to the future, Mr. Bettis is of the opinion that "it will not be a great length of time before we shall see very nearly all electric operations performed automatically, and workmen will be employed only to see that the equipment is kept in shape to function properly."

E. C. Sanders

Miller Street Automatic Substation of the Public Service Electric & Gas Co., of New Jersey

Serves Railway, Lighting and Power Loads—Transformer Capacity 9000 kv-a., Ultimate 20,000 kv-a.—Two 1500-kw. Railway Motor-generator Sets—Noise-proof Building Construction—Designed to Be Very Flexible in Operation—Supervisory Control Contemplated for Linking in Joint Operation with Five Other Substations

By N. L. Pollard
Consulting Electrical Engineer, Public Service Production Co., Newark, N. J.

N. L. Pollard

DISTINCTIVE among the automatic substations placed in service during the last two years is the Miller Street Substation of the Public Service Electric & Gas Co. It was designed and built by the Public Service Production Co., the Engineers and Constructors associated with the Public Service group of New Jersey. All the apparatus was furnished by the General Electric Co., and is automatically equipped to carry railway, lighting, and power loads. A front view of the building is shown in Fig. 1.

This substation is located in Newark approximately one and one-quarter miles south of the famous four corners of Broad and Market Streets, on the corner of Broad and Miller Streets, and fronts on Broad Street. It is in a district which is residential at present but will eventually have business places on Broad Street. It was therefore deemed advisable to install all the apparatus and equipment indoors and at the same time put the motor-generator sets in a noise-proof room separated from the remainder of the apparatus by a brick wall.

The apparatus installed is as follows:

One 6000-kv-a. bank of transformers, consisting of three 2000-kv-a., 13,200/2400-volt, 60-cycle single-phase self-cooled units, the high-tension sides of which are delta-connected and the low-tension sides star-connected;

One 3000-kv-a. bank of transformers, consisting of three 1000-kv-a. units similar to the above both in type and connections;

Two 1500-kw., 600-r.p.m. motor-generator sets, each of which consists of one 600-volt compound-wound direct-current generator mounted on the same shaft with a 4150-volt 60-cycle three-phase synchronous motor, the latter being designed to operate at a power-factor of 70 per cent at normal load and 80 per cent at 50 per cent overload for two hours;

Two 13,200-volt, 350,000-cir. mil 60-cycle three-phase incoming feeders;

Ten 4150-volt, 60-cycle, three-phase, four-wire power and lighting feeders, each of which is equipped with a reclosing automatic oil circuit breaker, three single-phase automatic induction regulators, and three single-phase 3.75-per cent reactors in order to limit the short-circuit current to a value well within the capacity of the oil circuit breakers;

Nine 600-volt railway feeders, six of which have a capacity of 1200 amp. and three of 2000 amp., each of which is equipped with a high-speed automatic circuit breaker:

One 60-cell Electric Storage Battery Co., type "E-5," 80-amp-hr. storage battery, connected through a grid-type battery-charging rheostat to one of the direct-current buses.

Space has been provided for an ultimate installation of five 13,200-volt incoming feeders and a transformer capacity of 20,000 kv-a.

Fig. 2 is a photograph of the two motor-generator sets with their starting equipment and load-limiting resistors located on the main floor, and with the switchboard for controlling the motor-generator sets and railway feeders mounted on a gallery in the same room. The insert shows the high-speed circuit breakers carried on supports above the back

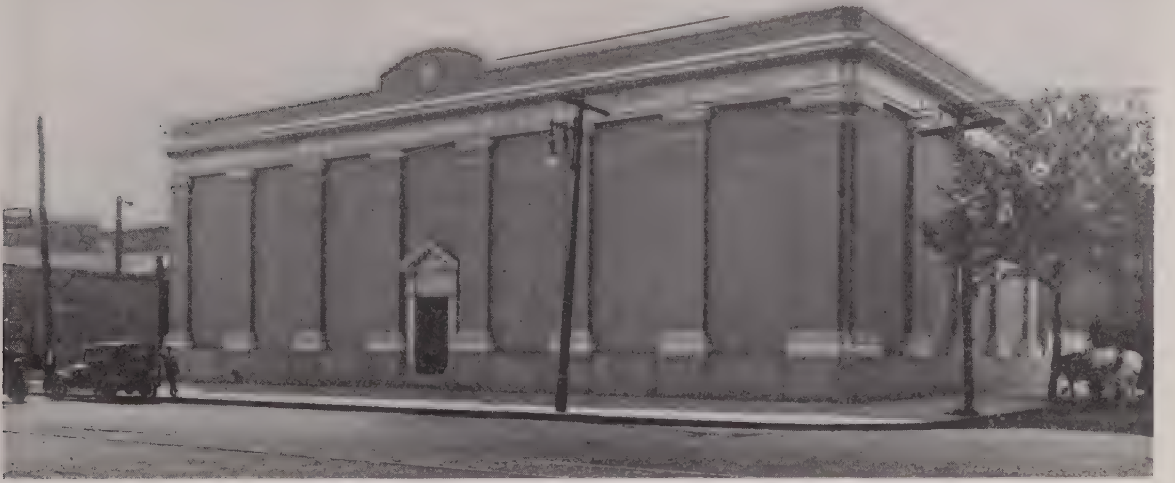


Fig. 1. Front View of the Miller Street Automatic Substation, Built to Serve Railway, Lighting, and Power Loads

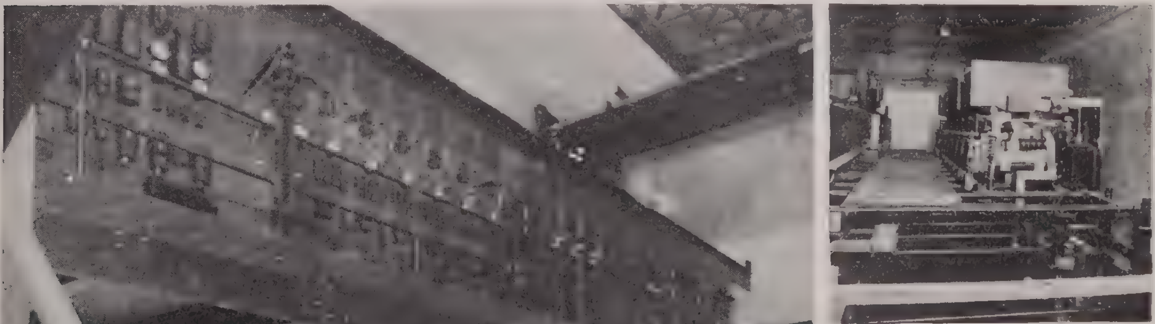


Fig. 2. Motor-generator Room Showing the Sets and the Switchboard for Automatically Controlling the Sets and Railway Feeders. *Insert:* High-speed Circuit Breakers Mounted behind the Switchboard

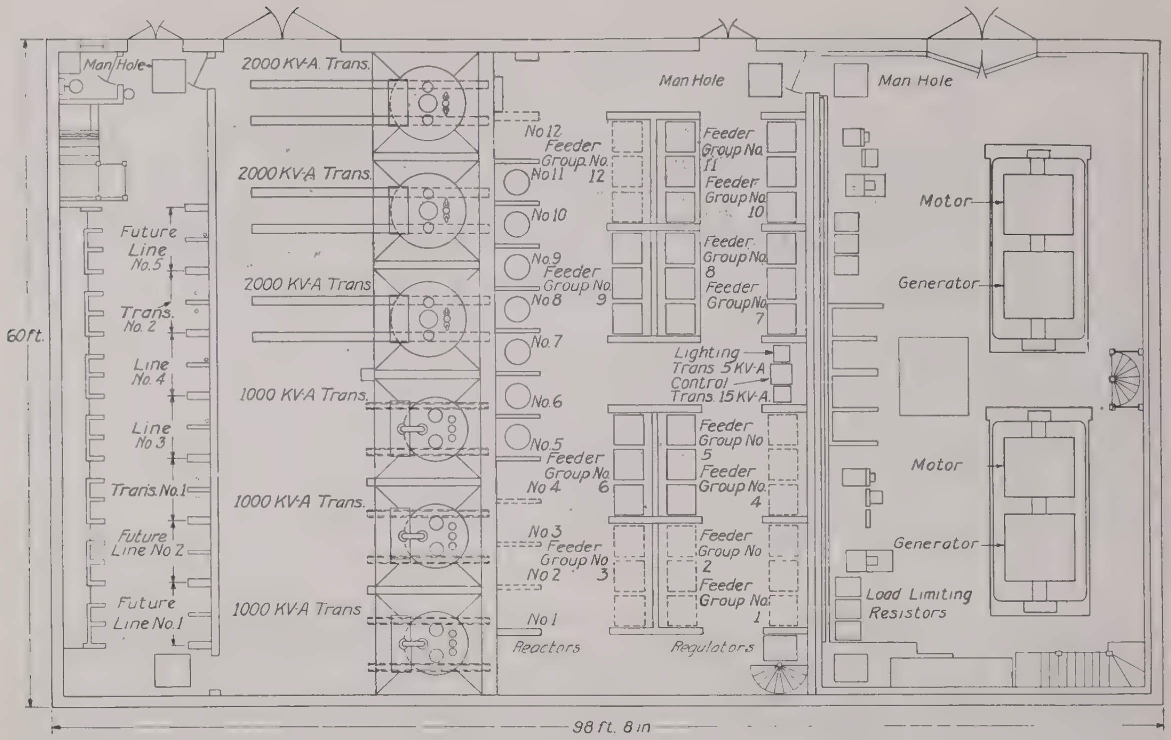


Fig. 3. Simplified Plan of the First Floor of the Miller Street Substation

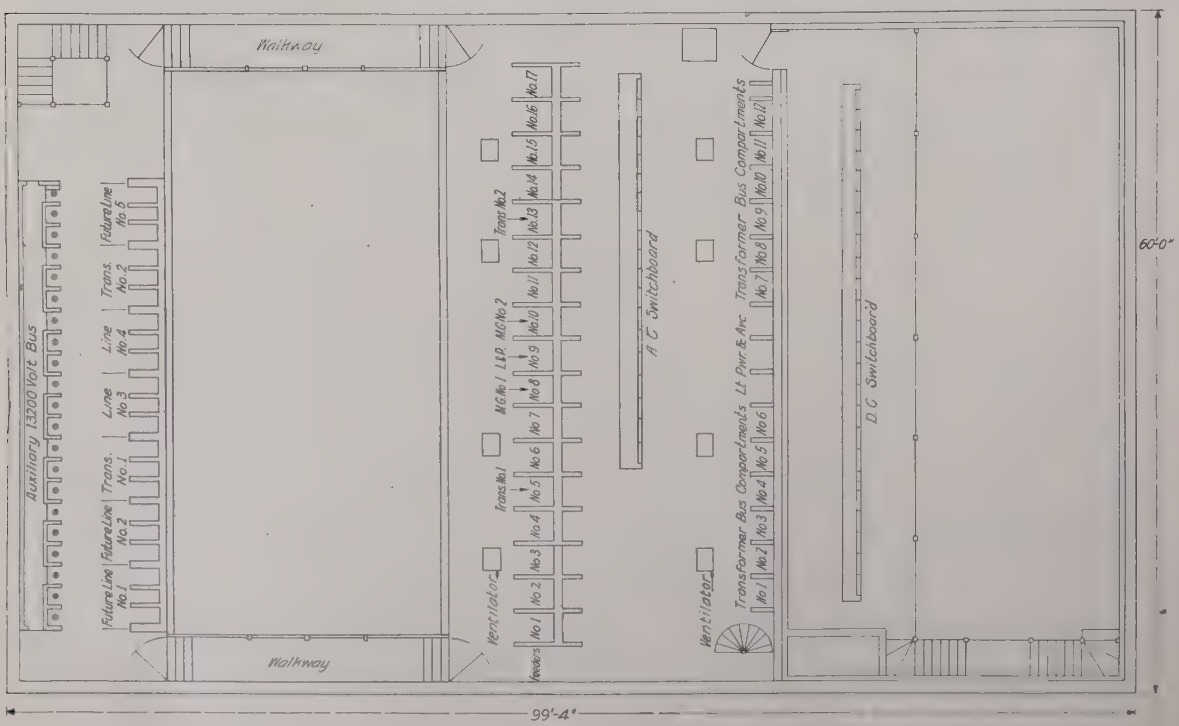


Fig. 4. Plan of the Second Floor of the Substation

of this switchboard. Plan views of the first and second floors and a cross-section through the substation are shown in Figs. 3, 4 and 5, respectively.

The building is of two-story construction, 60 ft. wide, 100 ft. long, and 30 ft. high. It is divided into four separate rooms, one for the high-tension equipment, one for the transformers, one for the 4150-volt feeder equipment, and one for the motor-generator sets and direct-current switchboard. This arrangement was chosen as being the most logical both from a construction and an operating standpoint.

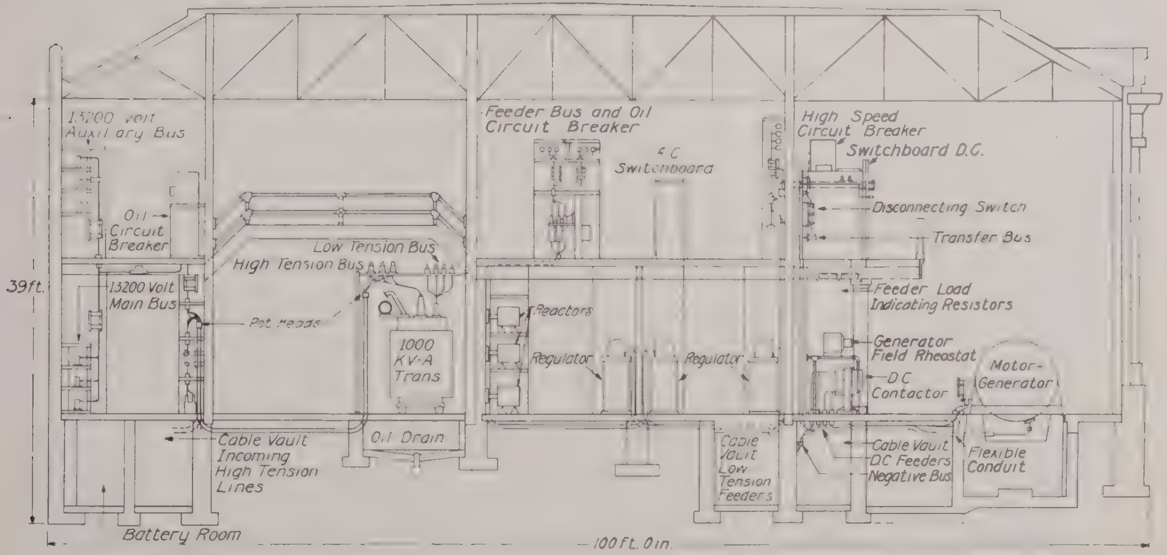


Fig. 5. Simplified Cross-section of the Substation

All the feeders connecting the substation to the system are brought in underground to concrete vaults beneath the main floor. There are three of these vaults, one each for the 13,200-volt feeders, the 4150-volt power and lighting feeders, and the railway feeders. It was thought desirable to segregate the feeders according to their classes of service and thus minimize any trouble which might occur.

In order to make the main connections, shown diagrammatically in Fig. 6, as flexible as possible, and to facilitate repair and maintenance, duplicate 13,200-volt and 4150-volt buses were provided. Two direct-current buses, one for each generator, were installed; these buses may be tied together by means of a circuit breaker but are normally operated at different voltages. In addition, there are two transfer buses, one for the power and lighting feeders and one for the railway feeders. A 1385-volt bus, used for starting the synchronous motors, may be connected to taps on either or both banks of transformers.

The two banks of transformers normally operate in parallel on both the high-tension and low-tension sides. They are controlled by automatic switching equipment through a multiple-pole double-throw switch which makes either bank lead and the other trail. When both banks are out of service, either may be put into operation independently of the position of this change-over switch. But, when the load on any transformer of the leading bank exceeds the normal value, the trailing bank is brought into service. If both banks are in service, the trailing bank is disconnected when the total load falls to such a value that the leading bank will be left in operation at 90 per cent of its capacity.

The two banks of transformers are provided with additional equipment as a means of protecting them against the following irregularities in operation:

(1) Overload
(2) Grounded or short-circuited windings
(3) Overheated windings
(4) Failure of the leading bank
(5) Throwing of the change-over switch.

The two motor-generator sets are also controlled by automatic switching equipment, and either set may be made the leading or trailing one. The generator of one set normally operates at 550 volts on the bus supplying power to comparatively short railway feeders; while the generator of the other set normally operates at 600 volts on the bus supplying power to the railway feeders running to farther outlying districts. The motors always operate in parallel when both sets are running. Starting indication for the leading unit is given by low bus voltage. When the load on this generator reaches 150 per cent of its normal value, the trailing unit is started by means of a contact-making ammeter.

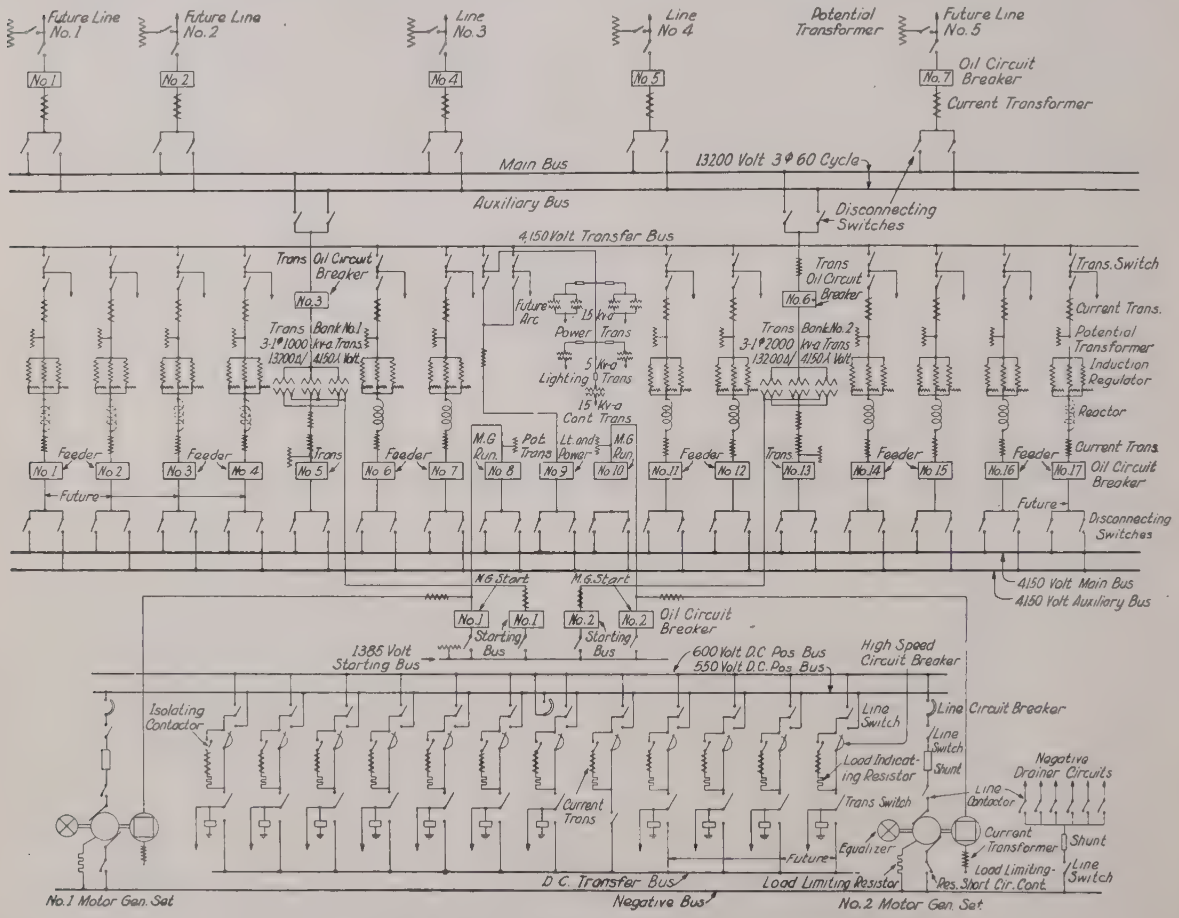


Fig. 6. One-line Diagram of the Principal Circuits in the Miller Street Substation

In addition to the automatic switching equipment that has been described, the two motor-generator sets are provided with numerous automatic devices to protect them during various operating troubles. If an overload occurs when either set is running, the series field of the overloaded generator is open-circuited and a load-limiting resistor is inserted in the line. Each of the two load-limiting resistors is in turn protected by a thermostat, which controls contacts to disconnect the overloaded machine from the bus in case the resistor becomes overheated. The other operating troubles included in the motor-generator protection are as follows:

(1) Grounded generator armature
(2) Reverse power
(3) Incorrect generator polarity
(4) Generator field failure
(5) Grounded or short-circuited motor windings
(6) Motor field failure
(7) Single-phase starting
(8) Overheated motor windings
(9) Low alternating-current voltage
(10) Over speed
(11) Incomplete starting
(12) Overheated bearings

Automatic protection has been provided for both incoming and outgoing feeders. The 13,200-volt incoming feeders are protected by reverse-power relays. The reclosing oil circuit breakers on the 4150-volt power and lighting feeders are equipped with tripping and closing relays so that, in case of a prolonged short circuit on one of these feeders, its circuit breaker is tripped, and reclosed after successive periods of five seconds, thirty seconds, and three minutes, and is then tripped and locked out until the closing relay is reset by hand. Each of the high-speed circuit breakers on the railway feeders, when tripped under short circuit, closes automatically only when the feeder is cleared. A thermal relay on each railway feeder provides for tripping the high-speed breaker if a large sustained overload is obtained which has a value less than that of the breaker setting. The same thermal relay closes the breaker when the feeder has cooled sufficiently.

As indicated in Fig. 1, there are no windows in the substation; the air for ventilating the motor-generator sets is taken in through a louvred opening in the roof of the building and passed through a series of baffles composed of flax-linum sheets. It is then carried through a large horizontal chamber, formed between the hung-ceiling of the motor-generator room and the roof of the building, to a vertical shaft leading to the basement. The ventilating fans, located beneath the motor-generator sets, force the air up through the sets and into the main room. The heated air is carried out through an opening in the ceiling of this room and finds its way to the atmosphere outside the building after passing through another series of flax-linum baffles.

The walls of the motor-generator room are lined on the inside with flax-linum keyboard nailed to studding. Approximately two inches of air-space is left between the brick wall and the flax-linum. The outside of the flax-linum is covered with one-half inch of ordinary plaster. The same method has been followed in sound-proofing the ceiling above the motor-generator sets, and the only door leading from the room to the outside is of the double refrigerator type.

In order to lessen the noise and vibration from the machines, each machine is grouted to a separate concrete foundation-block, averaging about seven feet in thickness. These blocks have been built up from a two-inch mat of anti-vibro block laid in hot asphalt, and have been separated on the sides from the floor of the motor-generator room by a similar mat four inches thick.

The air for cooling the transformers and induction feeder regulators, installed in another part of the building, as shown in Fig. 3, is brought in through louvres in the back wall of the building and emitted through ventilators in the roof.

The substation has been in service since the spring of 1924, and it is impossible for persons outside the building to detect any noise or vibration caused by the apparatus. The operation of the automatic equipment has been entirely satisfactory, but a study of supervisory control has been made and it has been decided that both the Miller Street Substation and the two other automatic substations now in service, as well as three others now being designed, will be controlled from a central load-dispatcher's office in the Terminal Building in Newark.

The placing of a synchronous machine in service is accomplished with certainty and dispatch by automatic control equipment

Automatic Hydro-electric Stations

Advantages of Automatically Controlled Hydro-electric Stations—Quick Availability for Load—Freedom from Hazards of Manual Stations—Lessened Labor Problem—Example of a Model Plant—How to Divide Load Economically with Steam Stations—Operational Factors to be Considered

By C. W. Place
Chicago Office, General Electric Company

C. W. Place

THE use of electrical power has now assumed quite a uniform rate of increase. Federal reports on its use are as accurate as can be obtained and show the production to be according to the curve in Fig. 1.

This production is being met by the installation of larger and more important steam stations at strategic points and the interconnection of systems, either on a power purchase basis or on a power exchange basis.

More and more operations in connection with this trend of development are being performed automatically or under the general supervision of some head operator. The voltage is regulated automatically, the lines are separated without human assistance in time of trouble, the draft in the boiler plants is regulated in accordance with the load. Throughout the load, the temperatures of ovens are maintained by automatic means, as are those of refrigerators, steel furnaces, steel tempering baths, and incubators.

In other words, the whole industry is being operated by instruments, relays, thermometers, pressure gauges, and other means of specially interpreting conditions, all under the eye of some sort of inspector, be he the head baker, the gang boss of the mill, or the farmer's wife who is interested in the young chickens.

There are, therefore, all sorts of precedents established for the automatic operation of any of the parts of the electrical industry; so that there now remains only the forming of a decision as to the particular interpretation of conditions to govern the operation, the taking of precautions so as to avoid trouble, and then the making sure that the advantages to be gained are worth the expense of doing what is contemplated.

Automatic Hydro-electric Stations

The particular branch of these varied applications to be considered in this article is that of the automatic operation of hydro-electric installations. In 1917 the first station having a protected control and carefully worked out sequence of operation was installed in Cedar Rapids, Iowa. Since then there has been a steadily increasing number of such installations; so that now the tendency has been quite well established, the economic balance under varying conditions more generally understood, and the proper weight of various factors better appreciated.

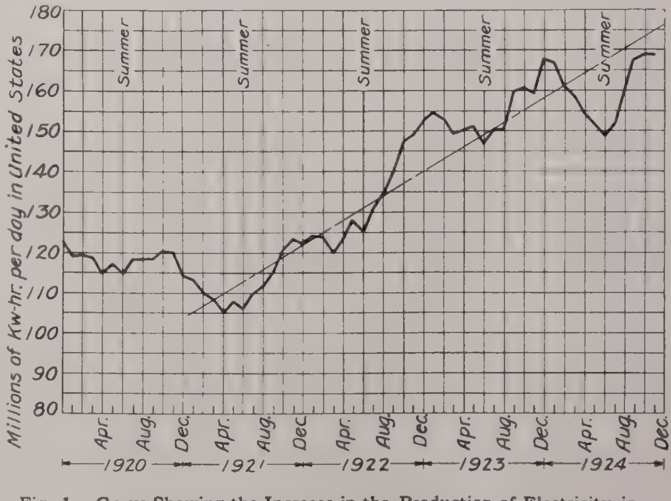


Fig. 1. Curve Showing the Increase in the Production of Electricity in the United States. (*Taken from Reports of the Department of the Interior*)

Outstanding Advantages

The first item of importance along this line is, of course, the consideration of whether the development of a possible water power would prove profitable by the automatic operation of a station where it could not if station attendants had to be employed. At first glance it would seem that the item of saving of operators' wages would be the determining factor. This saving however does not usually work out as the most important. The handling of the equipment by automatic means makes the equipment available quickly. It also insures that it will be on the line and picking up load without the indeterminate delay of manual synchronizing by an operator. It means that the equipment can be pushed up to its safe load limit without real danger of burning it out by a too high temperature of the windings; that it is protected against injuries that might otherwise result from a runaway or hot bearings.

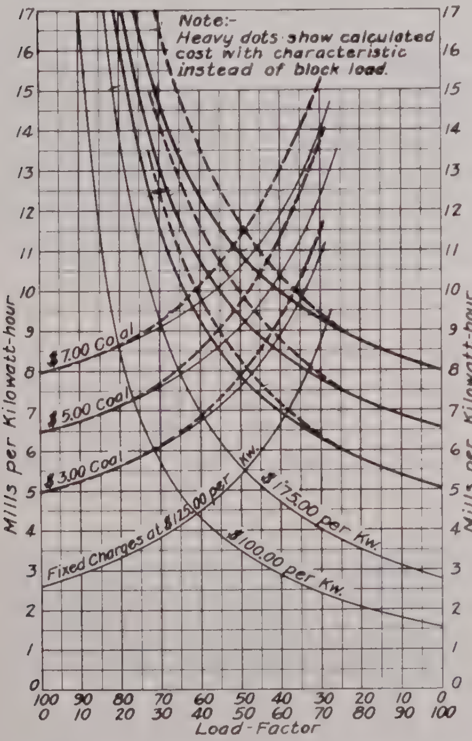


Fig. 2. Curves Showing the Cost of Producing Electricity at Various Load-factors by Steam and by Hydro Stations. (*Taken from Report of the Northeast Super-power Committee*)

Steam	Hydro
Fixed Charges 14 per cent	Fixed Charges 13 per cent
Operation $6 per kw-yr.	Operation $2 per kw-yr.
1½ lb. Coal per kw-hr.	

A more detailed consideration of some of these factors is enlightening. Take the time of getting on the line under load. This is as low as 17½ sec. for 2250-kv-a. units in a Wisconsin station. Since the real economy of a steam station can be best obtained by keeping the units on the line continuously under almost full load, and since the load of a public utility is around 60 per cent load-factor, this quick availability of an automatic hydro-electric station (or series of stations) causes it to be of considerably greater value than a corresponding manually-operated station. This naturally leads to the consideration of a hydro-electric station as a peak-load station instead of a base-load station; and instead of valuing its possibilities on the basis of primary and secondary power, which it may develop in the course of a year, it can properly be considered on the basis of the peak and off-peak power it can develop.

Relation to Steam Plant

It happens that the lowest daily peaks on systems occur when the hydro-electric supply is lowest in most sections of the country and the highest peaks take place when the hydraulic supply is highest, so this application dovetails in very nicely.

Along this line of reasoning, the curves in Fig. 2 will be of interest. These are taken from the report of the Northeast Super-Power Committee, and are copied from Plate No. 1 as calculated by the Federal Power Commission in May, 1924. The heavy full lines are what we have calculated as the value of hydro-electric power as peak power to a system to bring steam power up to various load-factors and correspondingly down in cost per kilowatt-hour, following the cost curves of the Commission. The Federal Power Commission curves were evidently calculated on block power. The dotted curves are estimated costs on the basis of characteristic system loads. It will be noticed how this changes the value of hydro-electric power and the relative importance of this as peak-load and base-load capacity. These probable values are without transmission costs, being considered at the generating station. This means that since the hydro-electric stations possible throughout the country are located in the valleys, they will average nearer the part of the load of the system of low load-factor than the large steam stations, and hence the transmission conditions favor such stations as peak-load stations.

All of these considerations mean that taking advantage of methods of control now available will allow a greater degree of development of present or possible sites and the operation of steam stations so they will produce their power most economically.

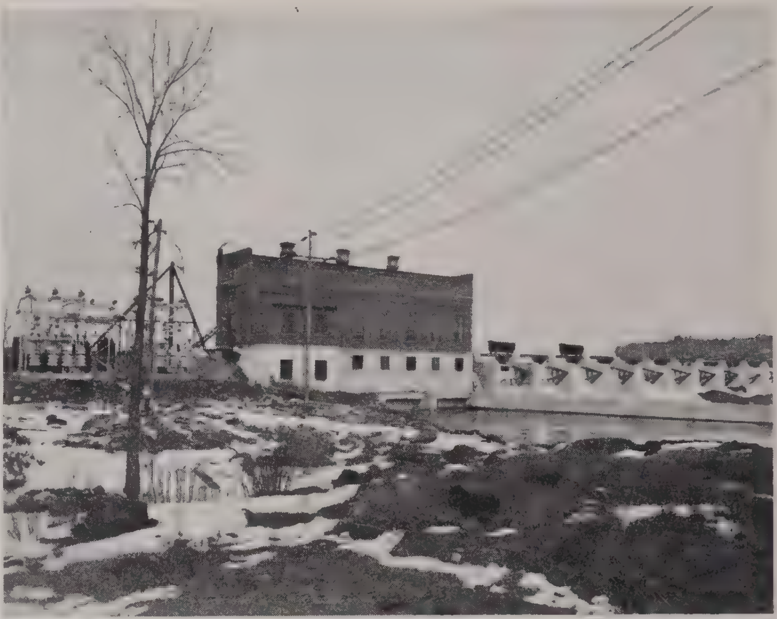


Fig. 3. Upper Merrill Power Plant of the Wisconsin Valley Power and Light Co.

Labor Situation

The next advantage of an automatically-operated plant over a manually-operated plant lies in the matter of labor turnover and the availability of labor. As systems extend, the type of operator must improve. It is one thing to operate a small station on a system immediately at hand, and another thing to operate a station as part of a large system. As the labor conditions become more exacting, the availability of men to operate the various stations becomes more of a problem; while the availability of men to inspect and maintain automatic stations is less of a problem. The interesting work of keeping equipment in condition to take care of itself attracts the type of men needed, while much greater inducements must be held out to the right kind of men to compensate for the monotonous part of an operating job in what appears a relatively unimportant station of the system.

The continual extending of systems makes the possible grasp of the situation by the operating crew an important item. Consequently, the automatic operation of certain parts relieves this strain on the members of the operating force and allows them more time at occurrences of trouble to take care of the remaining non-automatic equipment.

Quick Availability for Load

The arrangement of this peak-carrying generator capacity so that it will start up each time the system voltage is restored, after an interruption, gives quick load-carrying ability to a line without the delay of

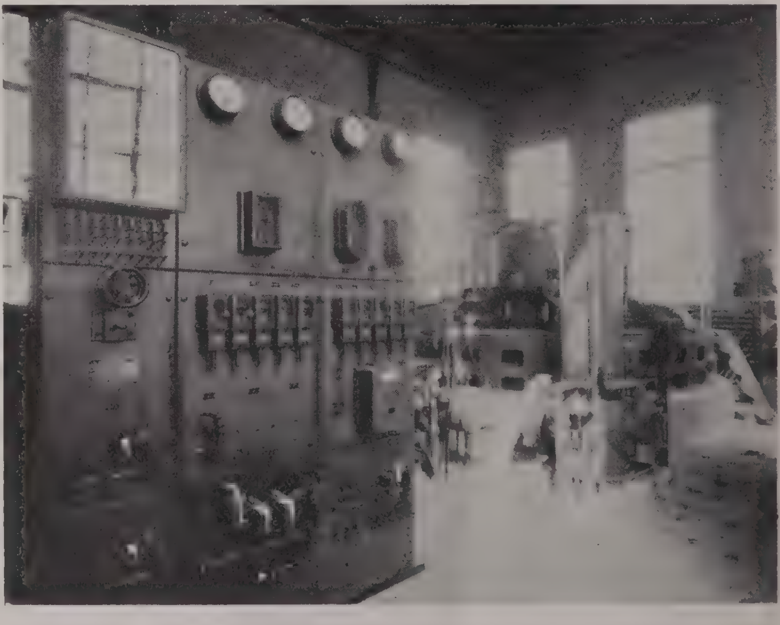


Fig. 4. Inside View of the Station Showing One Control and One Machine

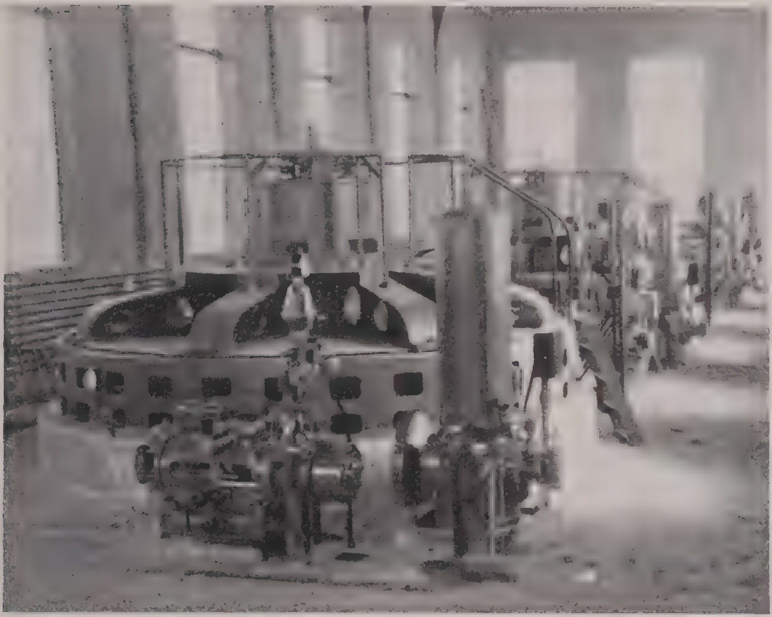


Fig. 5. An Interior View Showing the Three Machines

despatching the restoration and the greater time for manual synchronizing. This means that the use of a despatching system is not essential if the stations are made completely automatic. The system loads have very close to the same characteristics day after day with seasonal changes. The station can therefore be arranged to come on at the time of day the load builds up regularly; and from the relative values of the curves in Fig. 2 it might easily be worth while to let water go over the dam just before the heavy load comes on, in order that the pond may be full to give the maximum head, and hence the highest output during the peak.

The foregoing presents the different angles to be considered in evaluating an automatic hydro-electric station as compared with a manually-operated station.

A Model Plant

The trend which the construction is taking along this line is illustrated by the photographs of the Upper Merrill Power Plant, of the Wisconsin Valley Power and Light Company, which appear in Figs. 3 to 6 inclusive. It will be noticed that individual machine controls are located near the machine, the oil circuit breakers and buses being located in a separate room. This unit construction gives an arrangement which will easily apply for any number of machines.

The station is interesting in another respect; i.e., it is arranged so that the water will remain very close to the crest of the dam. This is done by gradually unloading a machine and then taking it off the line when certain water levels below the crest are reached. It is loaded up in the same gradual manner. The object of this is to disturb the frequency as little as possible in the process of taking off and putting on machines to meet this water condition.

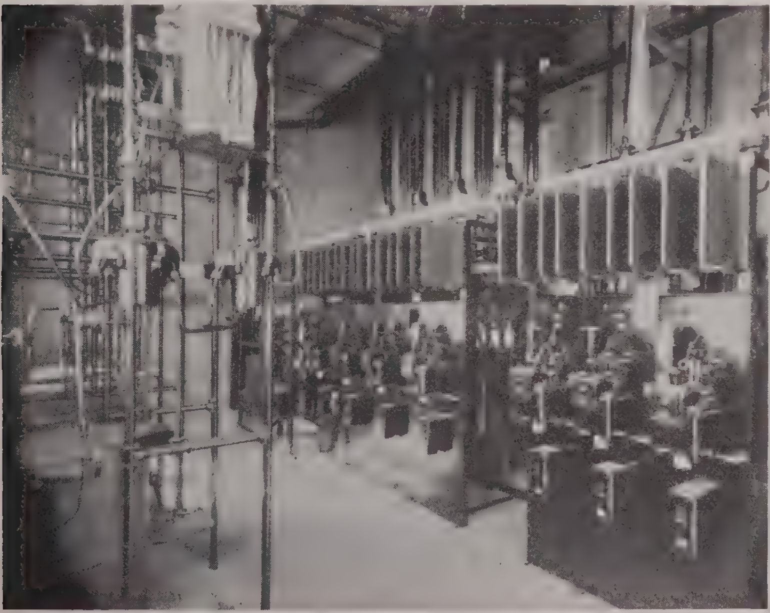


Fig. 6. A View Showing the Oil Circuit Breaker and Bus Room

Special Considerations

Other systems and stations have different problems, but if the special conditions are kept within bounds, the control can be easily arranged by slight additions to the standard as a base equipment. These special requirements should be minimized as much as possible. While the object of any such addition to the fundamentals is to make the station more nearly take care of peculiar conditions, these extras, if too numerous, would tend to make the cost too high compared to the benefits gained.

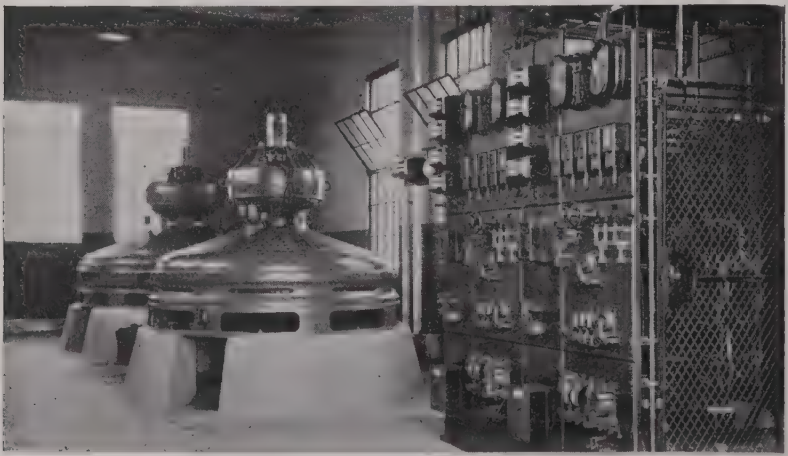
At most of the stations of the type shown in Figs. 3 to 6 there will be an attendant to care for the hydraulic conditions. This man will not be a station operator or switchboard man, but a guard and hydraulic man; and it usually works out that some of these extra conditions can be easily taken care of by this man as being more in line with his work than in line with the proper application of automatic control.

It is very interesting to see the working of this idea in the minds of different people connected with the industry. It will be found that most people have an exaggerated notion as to the importance of some certain condition. When this condition is discussed it usually develops that the whole matter resolves itself into the problem of getting the most possible kilowatt-hours out of a flow of water with a certain limited head available, and the obtaining of these kilowatt-hours at some particular time.

Another interesting phase of the subject is the fact that the smaller stations seem to pay good returns on their investment. They can be easily financed; they can be paid for out of earnings as the work progresses. They do not require as expert engineering as a large station; do not take as long to build and put into operation; and are therefore something that the regular organization can take care of. Large and relatively important generators operate perfectly, and from appearances at present there is no limit to the size that can properly be controlled by automatic means, just as long as it is of a size commensurate with the weight of the system. The methods to be used in the control should take this factor into consideration.

Conclusions

The use of automatic control for hydroelectric stations permits the development and handling of possible sites in a way that will allow the maximum degree of development, and hence the maximum power production for a given flow. This is brought about by the quick availability of the equipment and its freedom from damage hazard; hence its natural application as the means of carrying peak load. Thus its energy is more valuable when developed on this basis than it would be on a firm and secondary power basis.



Automatically-controlled Hydro-electric Station of the Continental Gas and Electric Company, Fullerton, Neb.

Automatic Substations of the Kansas City Power & Light Company

Changeover from Manual to Automatic Operation of Edison Three-wire, D-c. Substations—Lower Operating Cost and Greater Reliability the Incentives—Same Factors Later Determined a Like Changeover of A-c. Substations—Automatic and Manual Operating Costs, D-c. and A-c.—Expectations Fully Realized in Dollars, Service, and Satisfaction

By A. E. Bettis
Vice President, Kansas City Power & Light Company

A. E. Bettis

The application of the automatic substation to the central station industry has unquestionably been brought about by the demand for better service on the part of the customer and for improved economy and reliability of operation on the part of the public utility company. In manually operated substations highly trained operators were required and these stations had to be designed with large clearances for safety. In automatic substations it is not necessary to have large operating clearances and all the apparatus can be located strictly with regard to economy of space and material. Highly trained maintenance men to take care of the inspections, cleaning, and repairing of the apparatus cannot be dispensed with, however, although very few maintenance men are needed to care for automatic installations as compared with the number of men required to operate and maintain manual installations.

The men in charge of the maintenance of automatic equipment are relieved of the nerve-racking strain that attends emergencies in manual stations and that occasionally, in some cases of poor judgment on the part of the operators, are very costly to the company. Service performed mechanically by well maintained automatic equipment is furnished without practically any trouble. If any irregularity occurs, it is taken care of by apparatus especially designed to perform under such conditions. The maintenance man inspects his equipment and maintains it at times when no emergency exists, consequently rendering more efficient service to the company and greater reliability to the customer.

Automatic D-c. Substations

In 1921 it became necessary for the Kansas City Power and Light Co. to remodel its direct-current substations and provide additional capacity. The direct-current system at that time was an outgrowth of an old system that was uneconomical in every way. The battery reserve capacity was far from adequate and could not be relied upon to any extent in emergency which was the condition for which it was installed.

Investigations were made to determine the possibility of applying direct-current automatic synchronous converters to Edison three-wire 220-volt systems. It developed that up to this time no applications of any magnitude had been made. All installations were small isolated cases of machines operating independently and not being required to function with other automatic stations on a network. A thorough consideration of the apparatus to be used gave convincing evidence as to the reliability of such a system. Comparisons were made between the cost of manually operated substations with batteries and that of automatic substations without batteries, taking into consideration the saving in cost of attendance. This saving apparently justified the installation of the automatic equipment.

Reliability of service was another prime factor of consideration in deciding upon the use of automatic equipment. Calculations indicated that the duration of interruptions on the system which amounted to 45 minutes to an hour and a half with manually operated substations could be reduced to two minutes with automatic stations. Actual operation

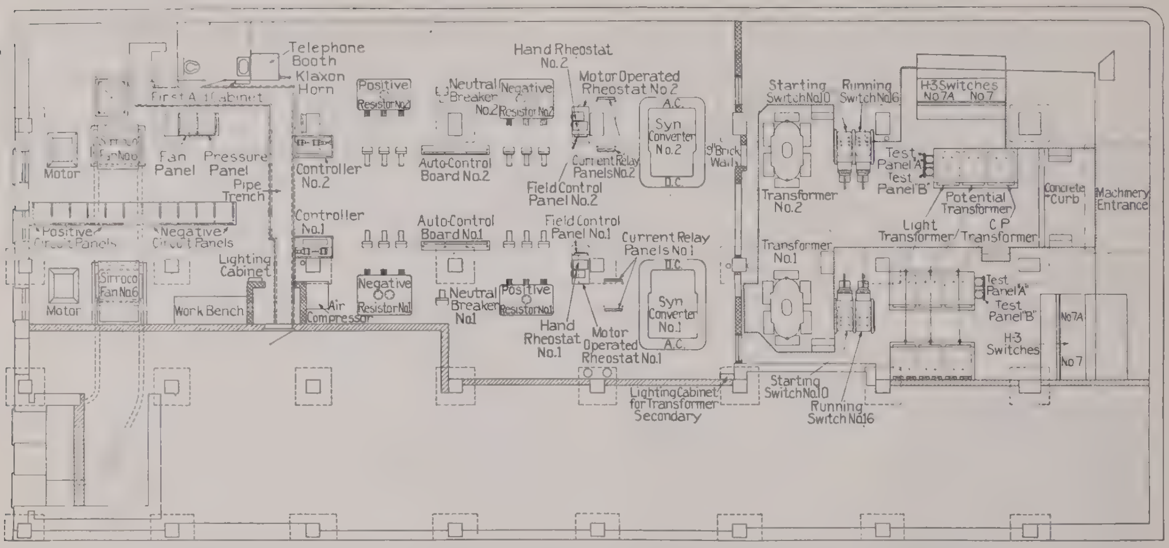


Fig. 1. Floor Plan of One of the Latest Direct-current Automatic Substations, Station "T"

in all cases so far has proved these calculations to be correct.

It developed that four substations with two 1500-kw. synchronous converters per station and one station with two 2500-kw. converters, located at the most economical distributing points on the system, should be used. The locating of desirable buildings that would permit stations in the basements was about the most difficult part of the task. It was necessary to make long-term leases to secure the best locations. No leases were made for less than 25 years.

The five automatic substations were designed for operation on three 13,200-volt feeders directly off the main power-plant buses. One of the feeders acts as a spare for the other two. The converters in the

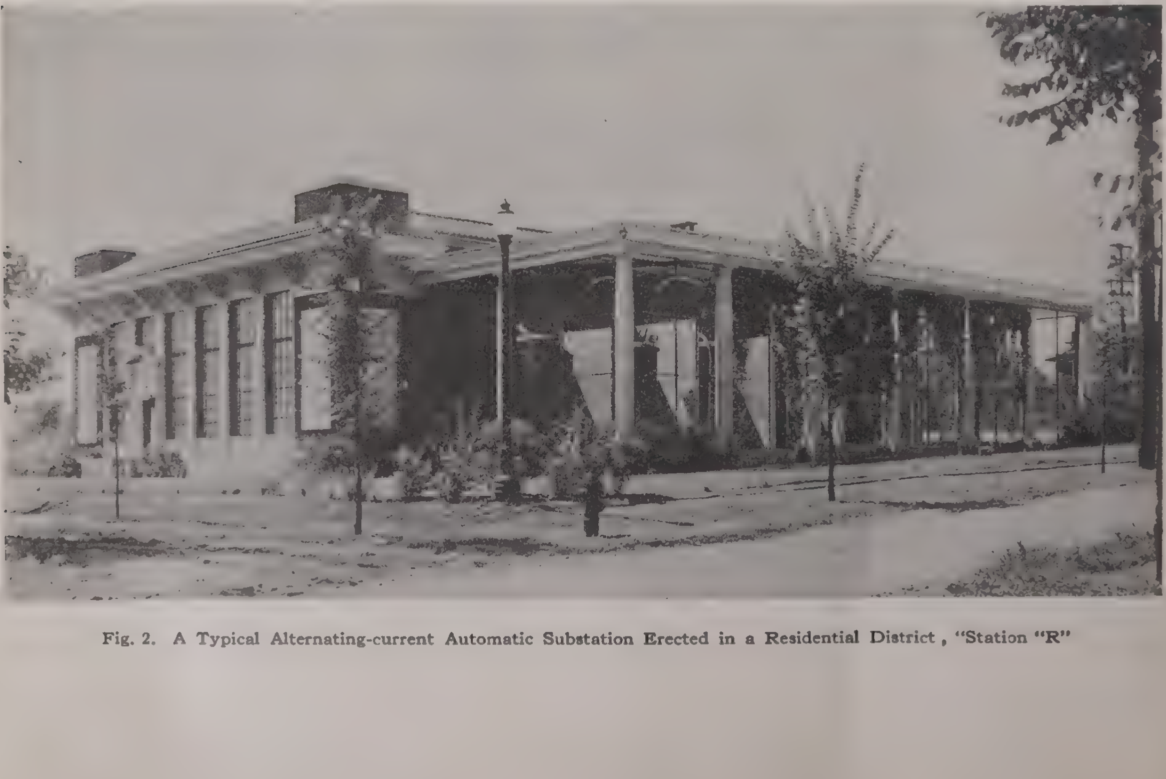


Fig. 2. A Typical Alternating-current Automatic Substation Erected in a Residential District, "Station "R"

stations are paralleled only through the system network. One machine operates on the high bus with long feeders and the other on the low bus feeding nearby customers on short feeders, the bus differential being approximately 4 volts. The direct-current feeders are so arranged that they can be transferred to the high or low buses by means of double-throw, single-pole switches. Fig. 1 is a floor plan of one of the most recent installations of these direct-current automatic substations.

There had been much comment on what would be the attitude of operators of large office buildings toward the noise of synchronous converters and oil circuit breakers in operation. This can be readily answered by the fact that two of the stations are located in the basements of 15-story office buildings; also, one in a local club and one in a retail store building. Another is in the basement of a 5-story office building. There has been no objection made by any tenants, owners, or operators of these buildings. No special construction was used except the ordinary reinforced concrete floor, walls, and ceiling.

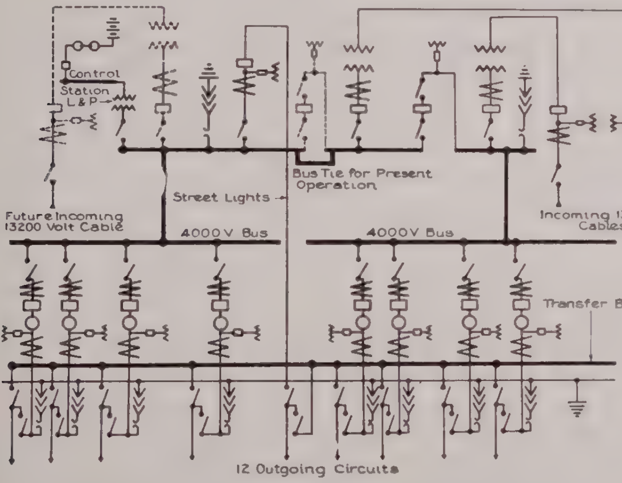

Control Station L&P
Street Lights
Bus Tie for Present Operation
Future Incoming 13200 Volt Cable
4000V Bus
4000V Bus
Incoming 13200 Volt Cables
Transfer Bus
12 Outgoing Circuits

Fig. 3. Single-line Diagram of the Automatic Substation Shown in Fig. 2

An essential matter to be taken care of was the ventilation of the substations. The difficult part of this problem was the disposal of the air. This apparently can be accomplished only by conducting it through ducts to the top of the building. The intake air is usually drawn in through sidewalk gratings and cleaned by passing through dry air screens.

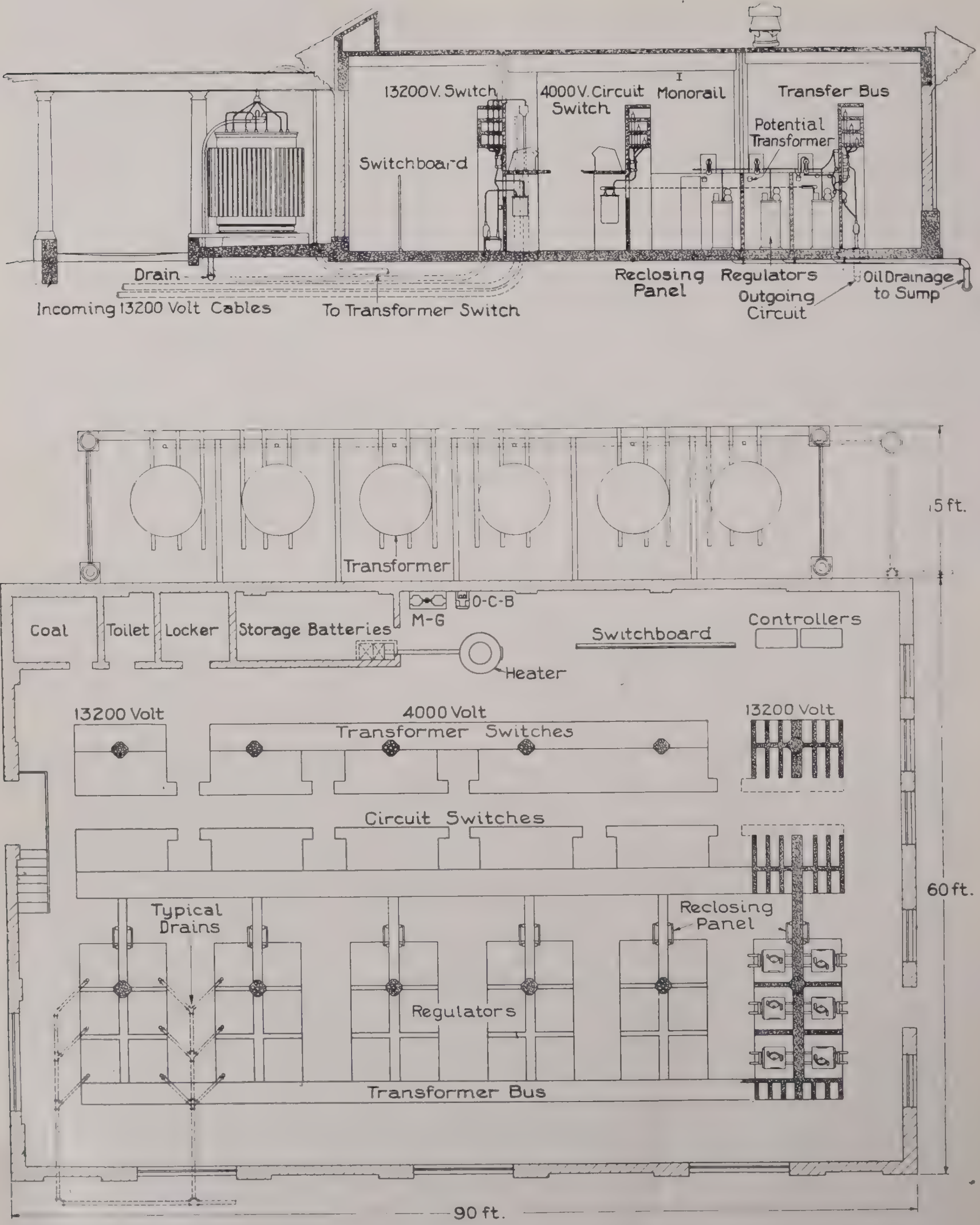
The first automatic direct-current station was placed in operation in September, 1922, and the latest one on January 1, 1925. All of these stations have performed to the entire satisfaction of the Company. The net saving in operating labor which was secured by using automatic equipment in place of manual equipment was approximately $20,000 per year. Tables I and II show comparisons of the Company's installation cost of manually-operated substations against those which are automatic, and also the cost of operation of the automatic stations.

Automatic A-c. Substations

Shortly after negotiations had been completed for the five direct-current automatic stations, it was found necessary to make certain additions and extensions to the alternating-current distribution stations. Plans were drawn for an alternating-current substation of 12,000-kv-a. capacity.

The calculated economy and good service deduced from the investigation that had been made of the direct-current automatic substations caused an investigation of the desirability of utilizing automatic equipment in the alternating-current substations. While the first cost was slightly higher, the better possibilities for continuity of service and economy in operating labor resulted in the definite decision to install automatic equipment in the alternating-current substations. Endeavor was made to apply ordinary automatic equipment to the alternating-current station to perform certain 13,000-volt feeder and 4000-volt circuit functions that would normally be taken care of by hand operation. The station was designed to operate from three 13,200-volt feeders from the power plant, each feeder to have connected to it a transformer bank of 6000-kv-a. One of the transformer banks and its cables was designed to operate as spare equipment. The secondary side of the transformers were connected to separate bus sections supplying radial feeders.

The 13,000-volt feeder and transformer operation is similar to that of the direct-current automatic substations in respect to the emergency and normal operation of removing transformers from service during light loads and replacing them during heavy



FLOOR PLAN

Fig. 4. Elevation and Plan of the Layout of Apparatus in the Alternating-current Automatic Substation Shown in Fig. 2

TABLE I
DIRECT-CURRENT SUBSTATIONS—INVESTMENT, OPERATING COST, AND LOAD

Stations	MANUALLY OPERATED—25 CYCLE			AUTOMATIC—60 CYCLE			
	Substation B	Substation G	Substation C	Substation V	Substation U	Substation W	Substation T
Investments							
Building & Land....	$40,539	$61,666	$47,311	$19,980	$43,396	$39,960	$62,193
Equipment	277,634	303,599	160,436	146,033	219,179	157,160	164,965
Total	$318,173	$365,265	$207,747	$166,013	$262,575	$197,120	$227,158
Expense							
No. of months......	12	12	12	12	12	12	In operation only 3 months.
Operation..........	$11,666	$10,676	$1,261	$818	$2,889	$721	
Equipment maint...	3,216	1,275	5,390	4,901	4,432	5,813	
Building maint.....		322	137	26	24	325	
Total	$14,882	$12,273	$6,788	$5,745	$7,345	$6,859	
Distribution							
Kw-hr.............	17,845,760	12,267,368	7,149,460	10,724,190	14,298,920	7,149,460	
Max. kw. load	5,917	4,902	2,247	2,607	4,361	2,247	
Installed capacity ..	5,750	4,300	3,000	3,000	5,200	3,000	3,000
Ultimate capacity ..	5,750	4,300	3,000	3,000	5,200	3,000	3,000
Cost per kw. installed	$55.334	$84.922	$69.248	$55.339	$50.495	$65.706	$75.719
Average							
Yearly expense.....	$13,577.50			$6,684.11			
Cost per kw. installed	$70.128			$63.301			

TABLE II
ALTERNATING-CURRENT SUBSTATIONS—INVESTMENT, OPERATING COST, AND LOAD

Stations	MANUALLY OPERATED—60 CYCLE		AUTOMATIC—60 CYCLE			
	Substation F	Substation P	Substation A	Substation R	Substation D	Substation E
Investments						
Land..............	$6,184.00	$6,397.00	$4,329.00	$2,553.00	$21,000.00	$31,805.00
Building...........	37,740.00	46,986.00	45,639.00	55,774.00	39,566.00	34,547.00
Equipment.........	131,908.00	161,258.00	132,361.00	129,093.00	140,122.00	166,287.00
Total..........	$175,832.00	$228,190.00	$182,329.00	$187,420.00	$200,688.00	$232,639.00
Expense						
No. of months.......	12	12	12	12	In operation only 3 months	12
Operation..........	$8,086.15	$7,656.46	$1,685.00	$1,077.00		$8,568.40
Equip. maint........	2,465.23	2,520.23	3,512.00	2,623.00		2,956.71
Build. maint.	776.55	468.73	877.00	324.00		414.73
Total	$11,327.93	$11,645.42	$6,074.00	$4,024.00		$11,939.84
Distribution						
Kw-hr., 4,000 v......	14,713,500	30,540,700	20,129,000	12,357,200		33,682,000
Max. kw. demand...	4,859	9,053	5,854	4,622		12,087
Present cap.........	12,000	12,000	12,000	9,000	15,000	12,000
Cost per kv-a. installed............	$14.650	$19.016	15.194	$20.623	$13.350	$19.386
Ultimate cap........	12,000	12,000	12,000	12,000	15,000	12,000
Cost per kv-a. ultimate	$15.860	$20.220	$18.200	$20.350	$18.830	$19.386
Cost per ultimate kv-a. less land .	$15.34	$19.69	$17.84	$20.12	$17.430	$16.73
Average............	$17.25		$18.46			

loads. The low-voltage or 4000-volt feeders are of three-phase, four-wire, with grounded neutral and single-element oil circuit breakers on each phase having their individual automatic panels with all relays and equipment.

The street lighting circuits have a separate automatic panel, energized by a time clock, for turning on and off the lamps at the proper time. The street lighting feeder is composed of an ordinary three-phase four-wire grounded-neutral circuit controlled by three single-element oil circuit breakers operated individually. Pole-type constant-current transformers for series operation are connected to the street lighting feeders. Fig. 2 shows a typical residence alternating-current automatic substation, of which Fig. 3 is a one-line diagram and Fig. 4 the floor plan used.

TABLE III

ALTERNATING-CURRENT SUBSTATIONS—NAME, LOCATION AND RATING

INDOOR TYPE

Station	Location (Kansas City)	TRANSFORMERS	
		No.	Ratings in Kv-a.
R	61st and Forest sts.	2	6000 & 7500
A	27th and Madison sts.	2	6000
D	6th and Penn sts.	2	7500
E	3031 Cherry St.	3/6000 1/7500	6000
			Total 66,000

OUTDOOR TYPE

Stations	Location	TRANSFORMERS		VOLTAGE	
		No.	Ratings in Kv-a.	Incoming	Outgoing
7	Turner, Kansas	3	100	33,000	11,000
10	Higginsville, Missouri	3	667	66,000	33,000
12	Holmes Park, Missouri	3	37.5	33,000	11,000
31	18th and Charlotte sts., Kansas City	3	150	13,200	4,400
			Total 2862		

The operation of the first automatic substations proved so successful that a decision was made to apply the equipment to the outdoor remotely located stations. The reclosing time of automatic stations being so short, only a few seconds, it was quite obvious that the application of automatic equipment to the remotely located stations would reduce to a negligible time the delays in restoring service to rural communities and outlying customers. It is generally known by operators that the flashing over of insulators to ground will blow fuses and trip oil circuit breakers, thereby isolating the customer from service until a trouble man can re-establish it. The duration of this interruption usually will be from 15 minutes to an hour and a half, depending on local conditions. Yet, in the great percentage of such outages, the circuits from these stations will close back clear. This quick re-establishment of service is what the automatic reclosing equipment performs for the station, the company, and the customer.

Since placing in operation its first alternating-current automatic substation, the Company has installed three alternating-current automatic stations of approximately the same capacity as the first one, and has changed over one manually operated station to automatic operation. Table III furnishes a list of the automatic alternating-current substations installed and in successful operation on the Kansas City Power & Light Company's system.

In the opinion of the writer, it will not be a great length of time before we shall see very nearly all electric operations performed automatically, and workmen will be employed only to see that the equipment is kept in repair to function properly.

Automatic Substations for Edison Service

Increasing Application of the Automatic Principle—Economics—Performance—Synchronous Converters—Motor-generator Sets—Voltage and Current Control—Restoration of Service

By H. A. McCrea

Central Station Engineering Department, General Electric Company

H. A. McCrea

AUTOMATIC control for various types of generating stations and substations has passed through its experimental stage, and has proved itself not only to be practical but in many cases to possess a distinct advantage over manual control.

Semi-automatic conversion stations for Edison stations were tried out in Detroit in 1912. While these installations were entirely successful, nothing further was done in the way of applying automatic control to substations for Edison service for several years. In the meantime, automatic control of synchronous converters and motor-generator sets for interurban railway service had proved very attractive from an economic and service standpoint. Schemes of automatic control and special devices were developed to meet the need in the railway field and the unqualified success of such installations again brought the matter to the attention of companies operating Edison systems or industrial plants.

The Kansas City Power and Light Company was the first to adopt a comprehensive automatic-station program for Edison service. In 1921 this company started to rebuild its substations and now supplies all its Edison service from automatically controlled stations.

During the past three years a number of Edison systems have added automatic equipment. It is significant that the selection of automatic control for certain substations on Edison systems is on the basis of performance. Several such installations are now in operation, and tests indicate that the equipment will meet the rigid requirements of the service.

Advantages of the Automatic Substation

The final cost of the installation, considering capital invested, fixed charges, operating cost and performance, is of greatest importance to a company considering the installation of a new station, or the changing of an existing station from manual control. In this connection it is to be borne in mind that automatic features practically eliminate the operating charge, and that while the maintenance and fixed charges are only slightly increased, the ultimate result is usually a marked saving. Also, it may be possible to locate the apparatus more economically when automatic control is used. For instance, if the operator's wages need not be considered, two or more low capacity substations might be installed instead of one large station, and this would permit more economical distribution and a saving in feeder copper. In some cases, the saving in copper due to subdividing the stations has been more than enough to pay for the additional cost of the automatic control and the additional cost of the stations.

Some companies have found that the use of service restoration features used in connection with automatic control has enabled them to operate without increasing the size of their batteries as their systems grew, while others have found it practical to dispense with batteries entirely. One company which uses automatic control extensively claims that the total cost of its automatically controlled installation is actually less than if hand-operated stations had been used.

From an operating standpoint, it should be noted that automatic switching equipment very closely follows the routine for manually controlled stations, with the additional precaution that the various devices are so interlocked that the operations must follow a predetermined sequence, which in the manually controlled stations must be left to the skill and diligence of the operator. Also, the automatic station is provided with protective devices not usually found in manually controlled stations, and which do not depend on the watchfulness of an operator. Temperature relays are provided which have the same heating characteristics as the machines and shut them down in case of overheating due to sustained overload; bearing relays to shut the machine down in case a bearing starts to overheat; and devices to shut down the machine in case of field failure, or grounding. All these protective devices are so arranged that they will shut down the apparatus on the indication of trouble and before any actual damage is done.

There is also the possibility of the operator doing the wrong thing in time of trouble in a manually controlled station, while with a properly designed automatic control equipment the proper sequence of switching operations must be followed to take care of the particular conditions as they exist at the time.

The following factors which enter into the selection of apparatus for conversion stations must be given consideration:

Synchronous Converter Equipment

The converter with its transformer is the most efficient form of conversion apparatus for 250-volt service. It has the lowest first cost, requires the smallest floor space, and because of the higher efficiency requires less air for ventilation purposes. With a given alternating-current voltage, the direct-current voltage of the simple converter is fixed within narrow limits (5 per cent plus or minus). On this account, its use must be limited to stations where not only nearly constant potential is held on the alternating-current system but also where the feeder runs are short so that constant direct-current potential can be held at the distribution point with a very small increase in the station bus potential. As the maximum direct-current voltage is usually required at the same time that the minimum alternating-current voltage is impressed, the voltage range of the converter must be sufficient to adjust for the sum of the alternating-current regulation plus the direct-current regulation required.

For a voltage range not exceeding plus or minus 15 per cent, the synchronous booster direct connected to the converter shaft is the accepted best method, even though it involves certain minor complications in the converter itself. A larger voltage range can be obtained with the converter by the use of regulating transformers, or tap-changing devices on the transformers. These devices involve additional complication of the apparatus as well as additional control equipment.

The addition of any form of voltage regulating device to the converter lowers its efficiency, increases the first cost and floor space, and requires more air for ventilation.

It is well known that any disturbance on the alternating-current system will tend to cause a converter to invert and that to protect the machine it is necessary to disconnect it from both the alternating-current and direct-current systems.

This is especially true where different converters on the system are fed from separate sources of alternating-current power, as in the case of a number of companies which operate 25- and 60-cycle alternating-current systems and feed part of the conversion apparatus from each system.

If a short-circuit should occur on the 25-cycle alternating-current system, the converters on this system would tend to draw power through the direct-current bus from the 60-cycle system, which, depending of course on the location and severity of the disturbance, would require disconnecting some or all of the machines connected to the 25-cycle system.

Some companies are making provision to limit the amount of reverse current by automatic devices which insert a block of resistance in series with the direct-current circuit on the indication of reverse current. This resistance is automatically cut out on the restoration of normal conditions. By this means they are able to carry the machines through a number of disturbances which would otherwise mean a complete shutdown and restart.

The synchronous converter has a narrow range of voltage control depending upon the type of machine selected and consequently it cannot limit the current without external means. Where load limiting must be provided for a converter, it is usually necessary to supply external resistance which can be cut out in one or more steps, as local conditions may require.

The addition of voltage-control and load-limiting devices to the converter removes some of the advantages of lower cost, less floor space, and higher efficiency, which are obtained with a simple converter; and it is a question which requires considerable study to determine whether the converter or synchronous motor-generator set would be the more advantageous for a given installation.

Synchronous Motor-generator Equipment

The motor-generator set can be designed for any voltage range which may be required, and it has the added advantage of greater stability and also that, as the alternating-current and direct-current machines are electrically separate, any disturbance is not transmitted directly from one system to the other.

Most of the motor-generator sets which have been supplied for Edison service during the past few years have been equipped with a differential series-field winding on the direct-current generator, which makes this machine inherently load limiting. The main field receives two-thirds of its excitation from the generator terminals and one-third from a separate source. This one-third separate excitation insures the stability of the generator at all voltages. The synchronous motor of the set is equipped with a high-duty amortisseur winding that will develop sufficient torque to pull the motor into step with full load on the direct-current generator. The characteristics of such a set when used in conjunction with the proper automatic control equipment are such that it can remain connected to both the alternating-current and direct-current systems regardless of short-circuits, loss of voltage, etc. This feature reduces to a minimum the time for resumption of service after a disturbance.

The synchronous motor-generator set also can be designed so as to supply a certain amount of leading kilovolt-amperes to the system, and can therefore be used for the purpose of raising the system power-factor, whereas the synchronous converter is limited to operation at or near unity power-factor.

The load-limiting characteristic of the direct-current generator allows it to be connected to the bus without overload protection on the direct-current end, and therefore the maximum service can be obtained without interruption. This feature together with the stability at low voltage, obtained by the partial separate excitation, are also invaluable in connection with service restoration which will be discussed later.

Substation Location and Type of Equipment

As a system develops, the voltage range required at the substation may be reduced because of the additions in substations and the shortening of feeder lengths. Similarly, by a greater distribution of substations on a less developed system the same results are obtained. The automatic station development makes possible this more logical and economical method of locating substations which, in addition to other savings, may permit the use of the simple converter with its low range of voltage.

One company which a few years ago had the opportunity to revamp its conversion equipment completely, followed this scheme with very good results. This company dispensed with batteries entirely and arranged its substations so that each station contained two synchronous converters, one feeding a high bus and one a low bus, each machine being fed from the power house over a separate alternating-current feeder. This in reality gives the effect of single-unit stations as no machines are paralleled directly on one bus. With this arrangement, a simple type of control can be used and each machine can be treated independently. Also, as all the converter stations are supplied from the same alternating-current system, any disturbance (with the possible exception of trouble on a feeder to a converter) will affect all machines equally. For this reason the converters on this system are not subject to reversals of current as might be the case where separate sources of power are used to feed different stations. The layout of this system justifies the use of converters.

Service Restoration

One important consideration in the selection of apparatus for Edison systems is that of service restoration. Most operating companies have more or less elaborate schemes whereby they hope to raise the voltage on the Edison system after a case of trouble so serious as to involve sufficient apparatus to cause a complete interruption to the 250-volt service.

On a large system there is practically no chance to drill the operators in the sequence of events called for in these instructions, as such interruptions are of rare occurrence.

On account of the difficulty of restoring service after a complete interruption, the operating companies have invested large sums in storage batteries by which they hope to maintain service. The output of these batteries is necessarily limited to a comparatively short time, and it is the practice of most Edison systems to allow the battery to discharge until the voltage drops to a certain minimum value. If the conversion apparatus has not been restored by this time, the battery is disconnected and the remaining capacity held in reserve to help in re-energizing the system. When the conversion apparatus is ready to be put back in service, the battery is again connected to the line, and if it has sufficient capacity it will bring the voltage of the system up to a point where the converters can be put on the line. It requires an extremely large battery capacity, however, to accomplish this with the simple type of synchronous converter, because the no-load voltage of the converter cannot be lowered more than 5 per cent below normal.

This 5 per cent voltage range added to the normal regulation will give a minimum full-load voltage of about 87 per cent on the converter, so that the system voltage must be raised to at least this value before the simple type of converter can be connected to the direct-current bus.

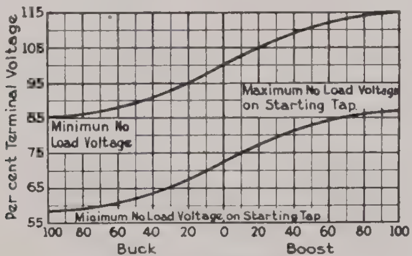


Fig. 1. Voltage Range of Synchronous Converter with Revolving Field Booster Designed for 15 Per Cent Buck or Boost when Operating on 72 Per Cent Starting Tap or 100 Per Cent Running Tap

The no-load voltage of the booster type converter can be lowered 15 per cent, which with the inherent regulation of the machine will give a full-load voltage of about 77 per cent. Further reduction in voltage may be obtained by means of some arrangement such as transformer taps to change the impressed voltage.

The starting voltage required for this 60-cycle booster type of converter is about 72 per cent of normal, and if provision is made for the starting connection to carry and switch load current, this connection can be used to obtain a lower voltage. This is usually accomplished by using a Y-delta connection with the proper voltage taps and high-tension switching.

If the starting voltage is 72 per cent and the voltage range of the converter is 15 per cent, a minimum voltage of 57 per cent is obtainable at no load and about 49 per cent at full load. Therefore, before such a machine can be put on the line it is necessary to raise the system voltage to at least 50 per cent before any converter can be connected. The gap from zero voltage to 50 per cent voltage must be taken care of by means of load-limiting resistance, storage batteries, or motor-generator sets.

If a sufficient number of machines can be connected to the system in this manner, the voltage can be raised enough to permit of similar machines being connected to the system with the booster rheostat in the full buck position and connected to the running tap on 100 per cent alternating-current voltage. Fig. 1 shows the no-load voltages which may be obtained from such a machine.

The synchronous motor-generator set with the differentially connected series-field winding and the partial-separate excitation is inherently stable and load limiting under any conditions and therefore can be connected to the system under any conditions. The current of this machine will be automatically limited to some maximum value and the voltage of the machine will increase to the value necessary to supply this maximum current. This characteristic makes this type of motor-generator set the ideal means of restoring service.

The differential series field of the generator is normally shunted by means of a circuit breaker which improves the regulation under operating conditions. This breaker is tripped if the voltage falls below a predetermined amount. Fig. 2 shows the characteristic curve for this type of machine. The values on this curve are obtained by varying the resistance of the external circuit and without changing the setting of the field rheostats. From the curve it will be seen that the generator will deliver approximately normal current at a very low voltage and continue to deliver this current as the system voltage is

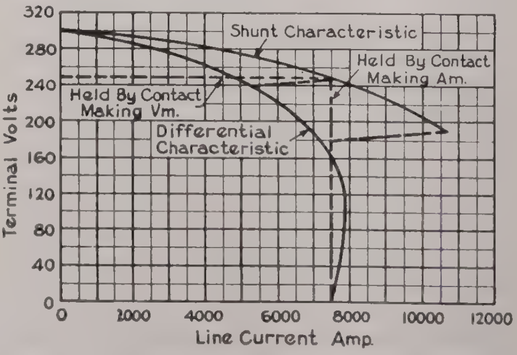


Fig. 2. Characteristic Curve for Direct-current Generator with Differentially-wound Series Field and Partial Separate Excitation

increased. By the addition of automatic voltage and current control devices, the current can be held at a constant value from zero to normal voltage.

Fig. 3 shows the general characteristic of the voltage-current curve of the average Edison system having 50 per cent lighting load and 50 per cent motor load. The break in the curve is the point at which the majority of the motor loads will be disconnected from the system by the low-voltage devices.

The output from a given substation is limited by the voltage on the station bus, the drop in the feeders from the station, and the voltage of the system at the point where the feeders connect to the network. By plotting a curve of the current and voltage for the total system and adding the drop which would occur in the feeders if all this current came from one station, a curve can be obtained to show the current supplied to the system from this substation at various bus voltages.

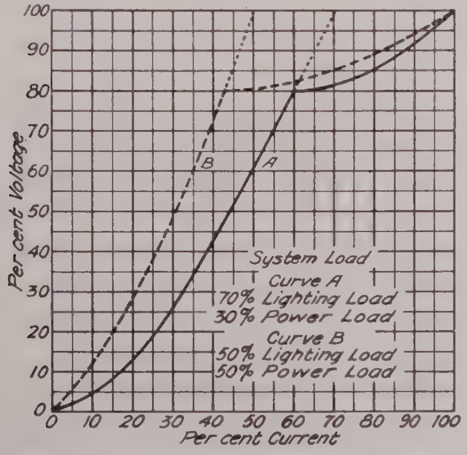


Fig. 3. Characteristic Voltage-current Curve for Edison System

Then if the characteristics of the machines are known, the amount of current which the station would tend to deliver can be determined and the amount of load-limiting resistance necessary to prevent this current from reaching values dangerous to the machines can be calculated. For the single-unit station it is a simple problem to figure the additional resistance which will be required to allow a synchronous converter operating at a given voltage to deliver a safe value of current to the system, and to arrange this resistance in steps so that as other stations assist in raising the voltage of the system a step of resistance can be cut out and still hold the current of the converter to a safe amount.

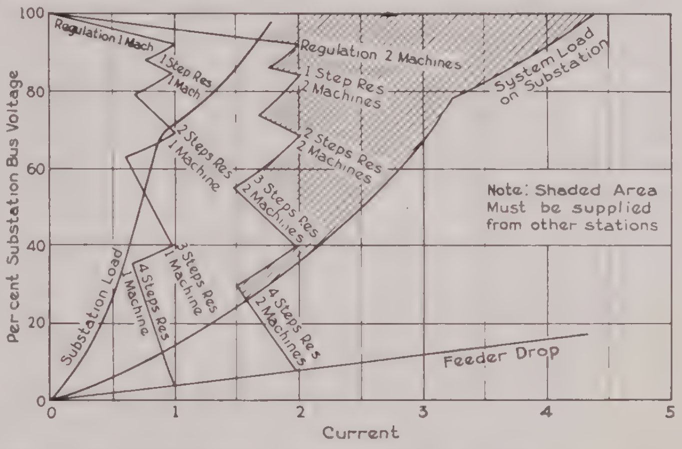


Fig. 4. Service Restoration. Current supplied from two-unit synchronous converter station with external load-limiting resistor

Fig. 4 shows the current values of system load and the current values of a converter station, due to cutting out various steps of resistance. The converters are connected to the bus with sufficient resistance in series to keep the current to a safe value under the worst condition. As the voltage of the system is built up, the current decreases and part of the resistance is automatically short-circuited. The current values and the resistance steps are so arranged that the current from the converter is kept below a certain maximum at all times. With the multiple-unit substation depending upon external resistance for load limiting, the steps of the resistance must be smaller and must be more carefully calculated, as not only must the current delivered to the system be considered but also the division of current between the machines themselves. This is especially true of the last steps, as the relays which operate the resistor short-circuiting devices on the various machines cannot be adjusted to operate at exactly the same current values and therefore the step of resistance on one machine will be cut out in advance of the other, causing this machine to take an increased current.

Fig. 5 illustrates the service restoration characteristics of a station containing one motor-generator set and one synchronous booster converter having a plus or minus 15 per cent voltage range, the transformers of this converter being equipped with an extended winding to obtain 72 per cent voltage. The 72 per cent tap is selected so that it can also be used for starting. Provision is made to switch the transformer connections under load. Intermediate taps are supplied to give smaller voltage steps, and advantage can be taken of these to reduce the voltage range and size of the booster, and thus compensate to some extent for the additional cost of the transformers and switching equipment.

With conditions as shown in Fig. 5, the motor-generator set alone supplying normal current would raise the station bus voltage about 12 per cent, of which 4 per cent is consumed in drop in the feeders from the station. The remaining 8 per cent would be the system voltage at the end of these feeders. The motor-generator set would continue to supply this current, raising the voltage as other machines or batteries on the system helped out to raise the system voltage.

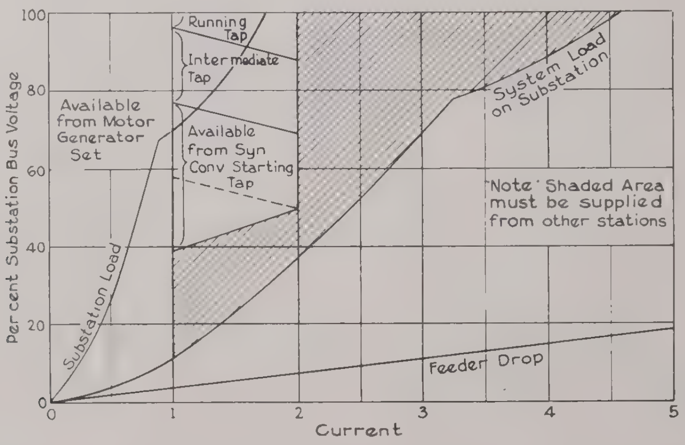


Fig. 5. Service Restoration. Current supplied from two-unit station consisting of one motor-generator set with differentially-wound generator and one synchronous converter operating on reduced voltage taps

The minimum no-load voltage of the converter when operating on the 72 per cent starting tap is approximately 58 per cent, which allowing 8 per cent for the regulation of the machine gives a full-load voltage of 50 per cent. The converter could be connected to the system at a voltage slightly below this, depending on the regulation of the other stations and the characteristics of the system load. The voltage of the converter is then raised by operating the booster-field rheostat so as to maintain constant current as other stations supply their share of the current and consequently raise the voltage of the system.

When the maximum boost on the low-voltage tap is reached, the connections are transferred to the next tap and so on until normal conditions are reached. The steps of a-c. voltage to accomplish this may be obtained by several different schemes, some of which are arranged to switch the transformer taps under load, while others depend on the buck and boost action of a voltage regulator.

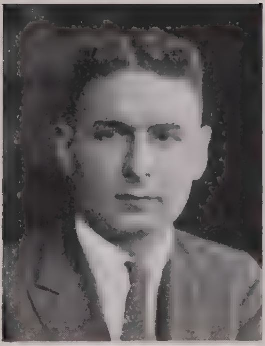
In general, these schemes of service restoration by varying the converter voltage are recommended for use only in single-unit stations or in stations containing a converter and a motor-generator set, on account of the possibilities of hunting between machines if used where a number of converters are connected to the same bus.

Properly designed automatic control equipment can be arranged to perform the function necessary for service restoration as well as to take care of the daily routine and protect the machines, and once correctly installed will pilot the conversion apparatus through a definite sequence for any sort of condition which may arise.

Automatic Equipment for Alternating-current Substations

Tendency Toward Small Automatic Substations Well Located with Respect to Load—Utility of A-c. Motor Mechanism—Variations in Reclosing Feeder Programs—Influence of Reclosing Cycle on Equipment Rating—Preferred-line Emergency-line Operation—Self-cooled Water-cooled Transformer Operation—Multiple Transformer Bank Operation

By J. F. Spease
Central Station Engineering Department, General Electric Company


J. F. Spease

During the past two years, central station companies have made more and more use of the automatic reclosing feeder, and this type of feeder has in turn proved to be reliable and has given satisfaction wherever used.

Quickness of mind, eye, and hand of the operator has ceased to be the requirement it once was, for the safety of electrical equipment is becoming less and less dependent on these attributes of man. Knowing what the ideal operator would do, it is but a step to substitute an automatic machine to take his place.

Before the days of automatic switching equipment, it was necessary to group a large number of feeders in a substation in order to keep the number of operators on the system down to a minimum. Since the perfection of the automatic reclosing feeder, the central station companies have been able to replace these large substations and operators with smaller automatic stations, more centrally located to the load they serve, which gives a more economical use of feeder copper. The operating costs of automatic stations show an appreciable saving, although the first cost is higher.

The development of the alternating-current motor mechanism has allowed the reclosing feeder to be used in these places where such equipment would be impracticable if a direct-current solenoid had to be used for closing the oil circuit breakers. The motor mechanism has been designed to close oil circuit breakers of voltages up to and including 132 kv. The power required to operate the motor mechanism is small and can be taken from a transformer having a 220-volt secondary.

Number and Time Interval of Reclosures

The control equipment for the motor mechanism is standard in its operation, and by changing the control relays any desired cycle of operation may be obtained on the reclosing feeder.

The number of reclosures and the time between them have not at the present time become standard with the operating companies.

From a survey of 44 operating companies using automatic reclosing feeder equipment, 29 of these companies use equal intervals between reclosures, and 15 use unequal intervals. Seventeen of them use a two-reclosing cycle, and 27 use a three-reclosing cycle.

The same operating company will use two different time intervals on different feeders. The time interval required between the opening and closing of the breaker is determined by the kind of load on the feeder. On power feeders, the time is less than that on lighting feeders. On large industrial loads, it is necessary to reclose the breakers as soon as possible, in order to keep the plant operating. A reclosing breaker that would operate fast enough to keep from dropping the motor load would be a great help to the industrial section. A disturbance of less than 0.5 of a second will not interfere with an induction motor carrying load.

Capacity of Oil Circuit Breakers, etc., on Reclosing Cycles

The duty imposed on a reclosing breaker is greater than that of the standard open-close-open plus open-close-open duty cycle. For this reason, the rated interrupting capacity of an oil circuit breaker must be reduced when used with an automatic reclosing feeder equipment.

The number of reclosures and the time between reclosing is the basis on which the interrupting capacity of oil circuit breakers is determined when used with automatic reclosing equipments.

All oil circuit breakers are rated on the standard duty cycle, open-close-open plus open-close-open, which has been approved by the Power Club, American Institute of Electrical Engineers and National Electric Light Association.

An investigation is now being made to determine the proper per cent relation in interrupting capacities which apply on other duty cycles. Until sufficient information is obtained, it will be advisable to send complete information on the interrupting capacity and reclosing cycle required to the manufacturers and obtain their recommendation on the size of oil circuit breaker for these requirements.

Due to the decrease in the rated interrupting capacity of oil circuit breakers in this service, it is sometimes necessary to install a breaker having a larger rupturing capacity than would be required if the breaker were used on a standard open-close-open plus open-close-open duty cycle.

For financial reasons, there is in many cases a desire to put into service a breaker of sufficient rupturing capacity to take care of most of the short-circuits that will occur on the feeder. At the same time, there is that possibility of a short-circuit occurring which will create a current beyond that which the breaker will successfully interrupt the required number of times. To keep from damaging the breaker under such conditions, a scheme has been worked out whereby the reclosing relays are locked out if the current is beyond that given for the reclosing cycle. This is accomplished by the addition of a current transformer and lockout relay which is operated by the excessive current. If the breaker does not stay closed after the reclosing cycle has been completed, the oil circuit breaker stays open until it has been inspected and the lockout relay reset by hand. The current transformer discriminates between heavy short-circuit current and moderate short-circuit current. The number of times the breaker recloses is determined by the current transformer and relay.

If reclosing feeders are equipped with induction voltage regulators or reactors, care should be taken to see that the apparatus is not damaged by overheating. If the time interval between reclosings is small and the short-circuit current is nearly equal to the safe allowable value of the regulator or reactor, there is a possibility of injury as the apparatus will not dissipate the heat generated by the short-circuit current in the time between reclosures.

Where reclosing single-phase feeders are used in large substations and where the substations are tied together, it is preferable to use direct current from a storage battery for control rather than alternating current. The battery gives a constant source of potential for tripping and closing all the breakers.

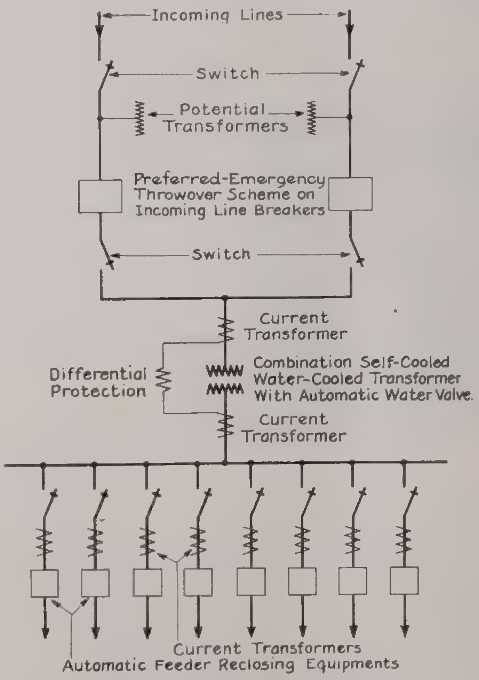

Incoming Lines
Switch
Potential Transformers
Preferred-Emergency Throwover Scheme on Incoming Line Breakers
Switch
Current Transformer
Differential Protection
Combination Self-Cooled Water-Cooled Transformer With Automatic Water Valve.
Current Transformer
Current Transformers
Automatic Feeder Reclosing Equipments

Fig. 1. Schematic Diagram of Automatically-controlled Preferred-line Emergency-line Method of Furnishing Continuous Service

Continuous Service by Preferred-emergency Lines

Where continuity of service is vital, many power companies have two tie lines between the substation and the source of power. Here, one line is designated as the preferred line and the other the emergency line. A throwover scheme is included which allows either line to be made the preferred or the emergency. The incoming lines can come from the same or different sources of power.

Upon failure of voltage on the preferred line and normal voltage on the emergency line, the preferred line breaker opens and the emergency line breaker closes. The emergency line breaker stays closed until normal voltage has returned to the preferred line. If the two incoming lines are from the same source of power, the preferred line breaker closes before the emergency line breaker opens upon return of normal voltage to the preferred line. If the two incoming lines are from different sources of power and are not in synchronism, it is necessary either to open the emergency line breaker before closing the preferred line breaker or check the phase displacement between the two lines before closing the preferred breaker.

As it is always desirable to reduce the number of power interruptions on a substation bus, the preferred line breaker may be closed before the emergency breaker is opened. This requires the use of an automatic synchronizing check where the two lines are not from the same power supply. The necessary equipment has been developed and is now being built for an initial installation where the preferred-emergency combination of incoming lines is used. If the equipment proves successful, there is expected a large field of application for it.

Where the incoming line voltage is such that a step-down transformer is required, many different methods are used to give continuity of service.

Control of Self-cooled Water-cooled Transformers

The combination self-cooled water-cooled transformer is used where water is available but at a premium and loads occur within the self-cooled rating of the transformer. Such a transformer costs more than a straight water-cooled transformer, but less than a self-cooled transformer. Here the amount of water flowing through the cooling coils is made to vary directly as the oil temperature in the transformer. The temperature of the oil may be used as a guide to operate the water controlling mechanisms by means of a thermal relay. As the temperature of the oil increases due to load, a water valve opens, gradually admitting just enough water to hold the oil temperature down to the predetermined value. The valve would begin to admit water before the full self-cooled rating was reached, except of course for the lag in oil temperature behind the current. Four degrees change in temperature is required to operate the valve from the closed to the full-open position. On the other hand, instead of turning on the full amount of water abruptly, it continues to supply only the necessary amount so that at loads higher than the self-cooled rating, but lower than the water-cooled rating, less than the full amount of water is admitted.

Control of Multiple Transformer Banks

Where three 3-phase banks of transformers are installed in one station, a scheme of operation is in use whereby a load increasing beyond the capacity of the first transformer bank automatically brings the second bank into service, and if the load increases beyond the capacity of these two banks, the third is placed in service.

If, for any reason, the second bank does not come into operation when called for, due to trouble or to the operation of the differential relays, the third bank will take its place in the sequence of operation.

The foregoing method of operation was developed for substations that are sometimes loaded only to the capacity of one bank of transformers and at other times to the extent of two or more banks. The procedure reduces the station losses at light-load periods.

In an automatic reclosing substation, more precautions are taken to insure the proper sequence of operation of the equipment than in a manually operated station. It has been proved that an automatic substation gives better service than a manually operated substation. Nothing is left to chance, as all operations are so interlocked that the proper sequence has to be gone through every time a breaker operates.

No human being is so alert as to equal the watchfulness of automatic protective devices

Automatic Distribution Substations of the Public Service Co. of Colorado, in Denver

The Company's Increasing Distribution by Automatic Substations in Denver—At Present 25,000 kv-a.—Description and Operation of Harrison Substation—Net Annual Saving by Automatic Operation $4500 Per Substation

By W. D. Hardaway
Chief Electrical Engineer, Public Service Company of Colorado

W. D. Hardaway

THE first automatic reclosing transformer and feeder substation of the Public Service Company of Colorado was placed in service in June, 1922. It consisted of one 5000-kv-a. transformer bank supplying three single-phase regulated lighting feeders and two three-phase power feeders. Shortly after completion of the substation, a second was placed in operation consisting of one 3000-kv-a. transformer bank, six single-phase lighting feeders, and two three-phase power feeders. Within a short time the first substation was enlarged to include a second 5000-kv-a. transformer bank, 15 single-phase lighting feeders, and 3 three-phase power feeders.

Two more substations of this general type were placed in service in 1924, and in the meantime three alternating-current motor-operated, automatic reclosing, sectionalizing oil circuit breakers were installed in 13-kv. suburban distribution service. Approximately 25,000 kv-a. of the Denver and suburban load of this company is now served through automatic equipment.

It is evident from the rapid increase in the use of automatic reclosing equipment by this company that the service rendered by the equipment has proved to be entirely satisfactory.

The automatic transformer substations supply city distribution circuits at 2300/4000 volts, four-wire, for lighting service, and at 4000 volts, three-wire, for power customers. The lighting feeders are operated as three single-phase feeders; and as the neutral is not switched, single-pole oil circuit breakers are used.

The transmission voltage to the substations is at present 13,200 but plans are under way for changing to 22,000-volt Y-operation and transformers recently purchased have been equipped with tertiary windings for absorbing the harmonics incident to Y-Y operation.

The transmission lines feeding two of the substations are operated as feeders from preceding substations and are equipped with automatic reclosing devices.

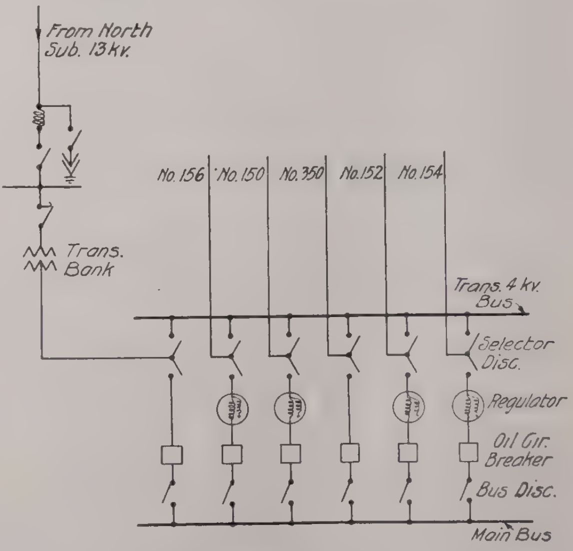


Fig. 1. One-line Diagram Showing the Scheme of Feeder Connections at the Harrison Substation

Harrison Automatic Substation

The most recently completed distribution substation, at 14th Avenue and Harrison St., Denver, is in a residential district, and serves a rapidly growing section of the city. As shown in Fig. 2, considerable attention was paid to the design of the building and yard to make the appearance of the substation pleasing to the owners of nearby residential property. This substation supplies 12 single-phase lighting feeders and one three-phase

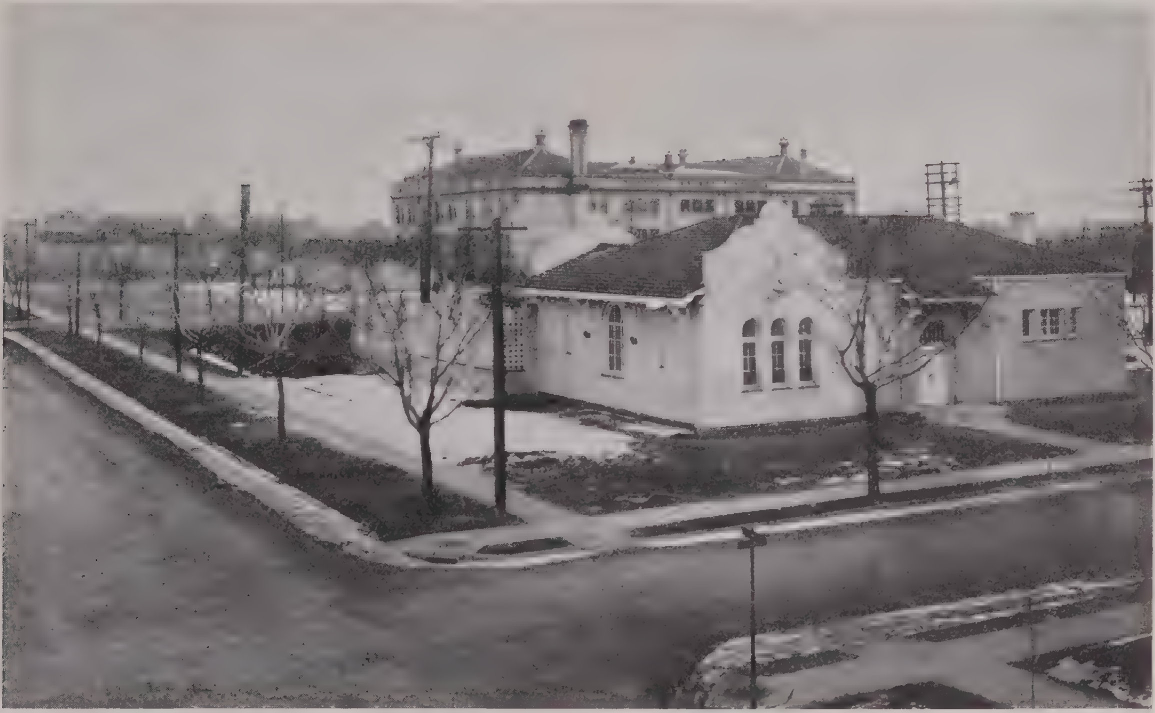


Fig. 2. General View of the Harrison Automatic Substation. An excellent example of what can be accomplished in combining nearby service with pleasing appearance in a residential district

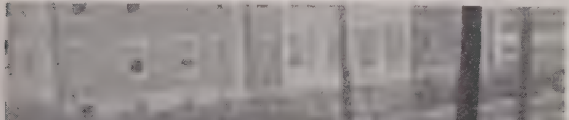


Fig. 3. A View Within the Yard of the Substation, Showing a Portion of the Outdoor Equipment

Fig. 4. The Switchboard Panels, Showing the Arrangement of the Automatic Equipment

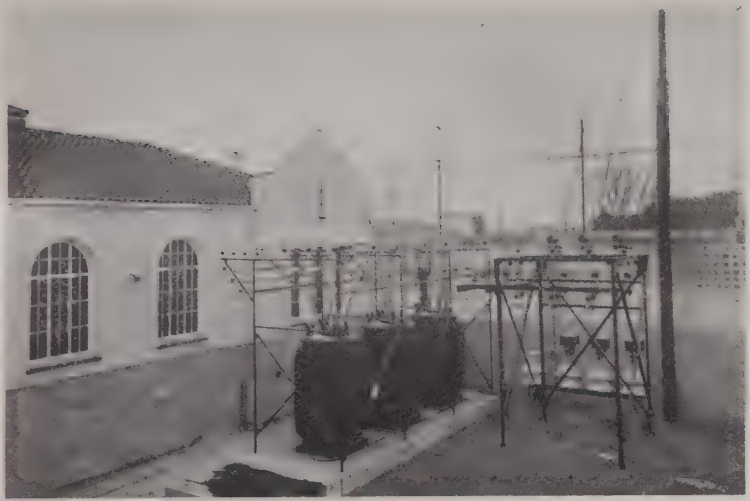


Fig. 5. Outdoor Equipment and Trellis Fence for Screening it from View

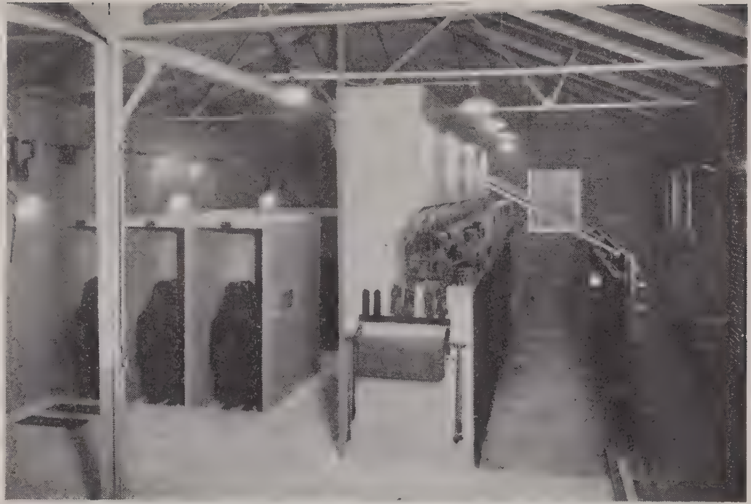


Fig. 6. Indoor View Showing the General Arrangement Within the Station

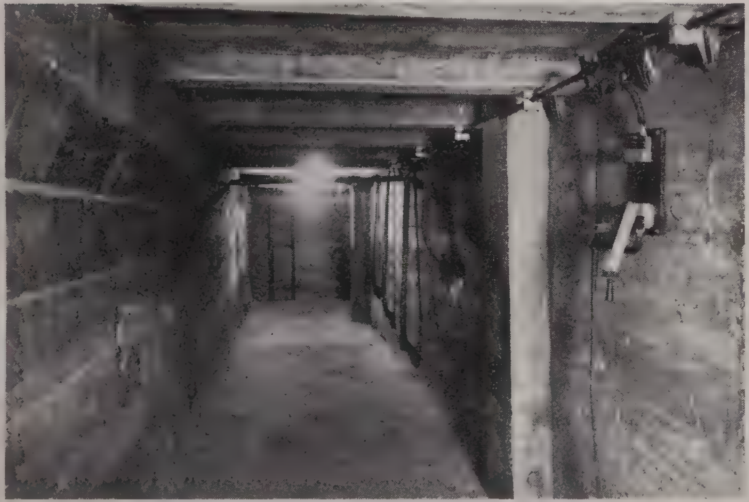


Fig. 7. Power Cable Tunnel, Showing Method Used for Bringing Feeder Cables to Desired Positions

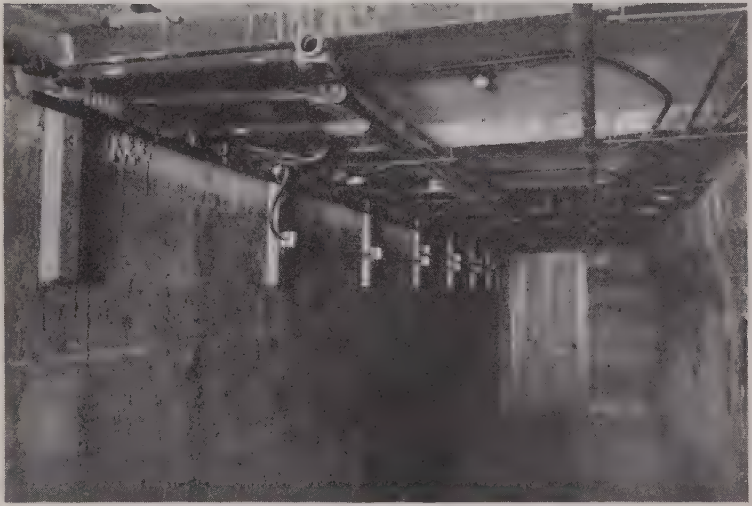


Fig. 8. The Control Cable Tunnel, Located Beneath the Switchboard Panels as Shown in Fig. 9

circuit at present, and is capable of being expanded to 24 lighting feeders and 3 three-phase feeders. A simplified diagram showing the scheme of power connections is shown in Fig. 1.

The 13-kv. lines are brought into the substation overhead, and terminate on a steel structure of minimum height. No high-tension oil switch is installed at present, but provision is made for an additional incoming line and two outgoing 13-kv. lines, with space for breakers and control equipment.

The transformer bank is rated at 3000-kv-a. self-cooled, 5000-kv-a. water-cooled, and is equipped with a thermally-operated water valve. The transformers are installed outdoors on a concrete mat, with a pipe framework supporting copper tubing buses, Figs. 3 and 5. A tertiary bus is provided for the delta connection of the tertiary winding. Space is provided for a second similar bank and a spare transformer.

The outdoor equipment is installed at the rear of the substation building, in a graveled yard, five feet below the street level, and a trellis fence effectively screens it from view, Fig. 3.

The low-tension leads from the transformer bank enter the substation building in three-conductor lead cable, and are connected to selector switches in the transfer bus structure, at the rear of the building. From the selector switches, single-conductor cable runs under the substation floor to the transformer oil circuit breaker in the main bus structure.

Lighting feeders are supplied from the main bus, through single-pole oil circuit breakers, and single-phase induction feeder-voltage regulators, to the transfer bus structure, and from it in three-conductor cable through the cable tunnel and underground duct to terminal poles.

Brush contact, indoor type oil circuit breakers and 46-kv-a. induction feeder-voltage regulators are used, Fig. 6. The incoming 13-kv. lines and 2300/4000-volt feeders are protected by oxide film lightning arresters.

One wall of the power cable tunnel, Fig. 7, contains nine four-inch fibre ducts cast in the tunnel wall. The concrete mix used was "rotten" to permit opening the ducts at any point and terminating any feeder cable at any position on the transfer bus. This arrangement permits maximum flexibility in expanding the substation or in rearranging the feeders. The neutral bus is carried in the power cable tunnel.

The transfer bus consists of three 750,000-cir. mil varnished-cambric braided cables in fibre duct. By the use of double-blade double-throw selector switches, any feeder or the transformer bank circuit may be used for energizing the transfer bus, and any feeder or the entire substation may be carried on the transfer bus. This arrangement permits routine inspection of the breakers and regulators, and test operation of the automatic equipment, without interruptions to service.

Concrete cells were built for the voltage regulators, with space on top of the cells for reactors if they are found necessary. The bottoms of these cells were dropped six inches below the floor level to provide an oil sump, and an oil drain was supplied to take care of burning oil in the event of a regulator failure.

The regulators are set on six-inch I-beams, which improves ventilation and brings the regulators flush with the floor for convenience in handling.

An air duct with openings at each set of regulator cells runs the full length of the building. This duct, in conjunction with a ventilator in the roof, supplies a flow of cooling air for the regulators.

The oil circuit breakers are installed in a monolithic concrete structure as shown in Figs. 6 and 9. Both the main and transfer bus structure have doors completely enclosing live parts. These doors are made of wood frames with "Sheetrock" panels. This type of bus structure has been used in all automatic substations in Denver, and has proved economical and very satisfactory.

The switchboard panels, Figs. 4 and 9, carry the automatic reclosing and protective relays, breaker control switches with indicating lamps, watthour meters, and demand meters. No indicating instruments are provided except for the transformer bank and operating battery. The reclosing operation, controlled by alternating-current motor-driven timers, is set to close a feeder breaker within 15 seconds after the first trip-out; and if the trouble persists, to reclose a second time in 45 seconds and a third time in 90 seconds; then to lock out until reset by hand. The timing is variable, and any desired division of the two and one-half minutes required for a complete cycle of timer operation may be used, but it is believed that the foregoing schedule represents a desirable compromise between the minimum interruption to service and the maximum duty on the oil circuit breakers.

One three-phase four-wire feeder is controlled by this station which serves 15 pole-mounted constant-current transformers supplying street lighting circuits. This feeder breaker is controlled by a time switch and is automatically reclosing during the hours the circuit is energized. The time switch also controls interior and exterior lights at the substation.

A 750-watt charging motor-generator set "floats" on the operating battery at all times. Contactors are provided for automatically disconnecting the generator from the battery if the motor supply circuit should fail.

This substation is General Electric equipped throughout and has never failed to operate satisfactorily.

The Public Service Company of Colorado has found that the first cost of automatic reclosing equipment is not materially greater than that of manual equipment after adding to the latter the cost of the necessary additional building space, heating equipment, and conveniences for operators. The maintenance costs of the automatic substation are somewhat higher due to additional equipment and to the expense of semi-weekly inspection. However, this item deducted from the saving in operators' wages leaves a net annual saving of approximately $4500 per substation. The reduced costs permit closer spacing of substations, with relation to load density, more economical use of distribution copper, and improved service to customers.

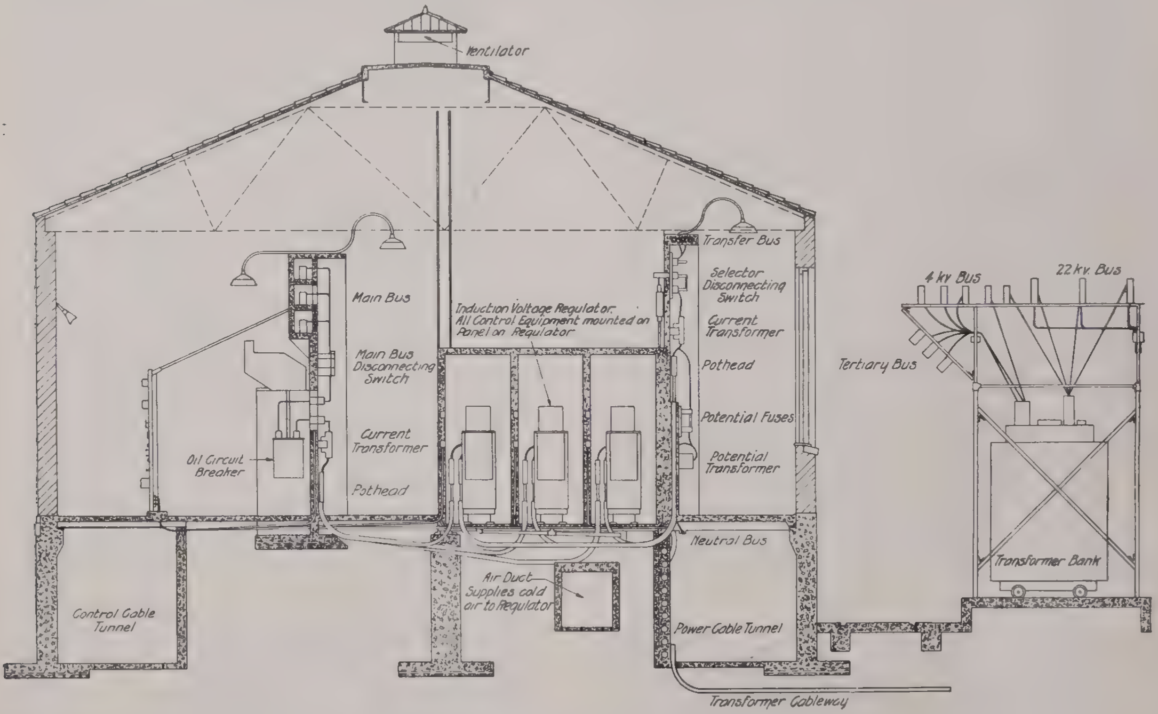


Fig. 9. Cross-sectional Drawing of the Harrison Automatic Substation. The front of the building is at the left and the yard at the right

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Maximum service is assured on feeders equipped with automatic reclosing devices

Automatic Synchronous Condenser at the South Works of the American Steel & Wire Co., Worcester, Mass.

An Example of Automatically Maintaining Good Power-factor—Simplicity the Keynote of the Design—Description of the Equipment and Control—Temperature Troubles Overcome

By E. B. Collins

Assistant Electrical Engineer, New England Power Company

E. B. Collins

IN 1923 the American Steel & Wire Company, one of the larger customers of the New England Power Company, decided to materially increase the proportion of its electrically-driven load. The normal supply of electrical energy was being furnished at 13,200 volts over a single circuit of 2/0 copper from the Millbury Substation of the New England Power Company, a distance of some 5½ miles. There were also two tie circuits connecting with the Webster Street Station of the Worcester Electric Light Company, consisting of a 4/0 underground cable some 13,000 ft. in length and a somewhat longer 2/0 cable.

In contemplating this increase in load, with the possibility of even further increases in the future, it was evident that the foregoing connections were inadequate.

There were two means by which the increased load could be handled; viz., by installing additional 13,200-volt circuits or by building a 66,000-volt line from Millbury to a substation to be located on the American Steel and Wire Company's property. There were advocates of, and good reasons for, each of the two plans but it was finally decided to build an additional 4/0, 13,200-volt circuit from Millbury and to handle the extra load at that voltage.

It was recognized that in case one of the feeders should be out of service, it would be impossible to maintain satisfactory voltage with a load of lagging power-factor. The power company had already installed on its system 40,000 kv-a. in synchronous condenser capacity; and inasmuch as a high power-factor for this new load was necessary to enable the power company to furnish satisfactory voltage, and by contract a power-factor of not less than 80 per cent was required from the customer, an arrangement was agreed upon whereby a condenser of proper size would be installed by the power company which would satisfactorily meet both requirements.

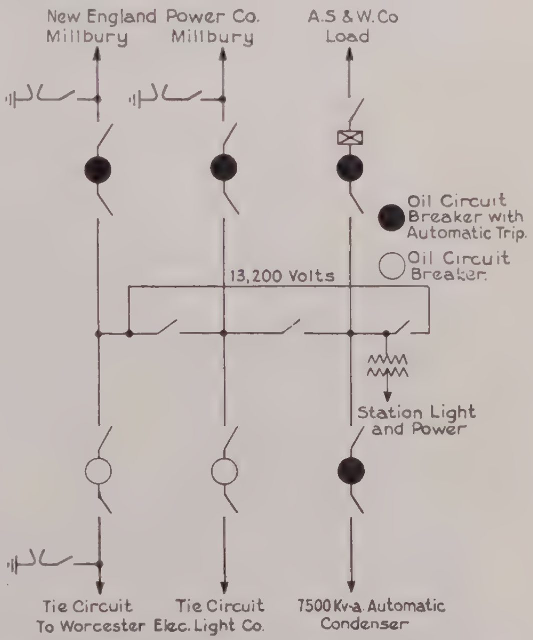

Fig. 1. One-line Diagram of the Outdoor Feeder Connections at the Automatic Synchronous Condenser Substation

In order to eliminate the necessity for any attendants, a condenser with automatic control was installed. This has a rating of 7500 kv-a. at 13,800 volts. The customer supplied a suitable brick building and concrete foundations; and a six-circuit outdoor galvanized-steel switching structure was installed by the power company adjacent to the

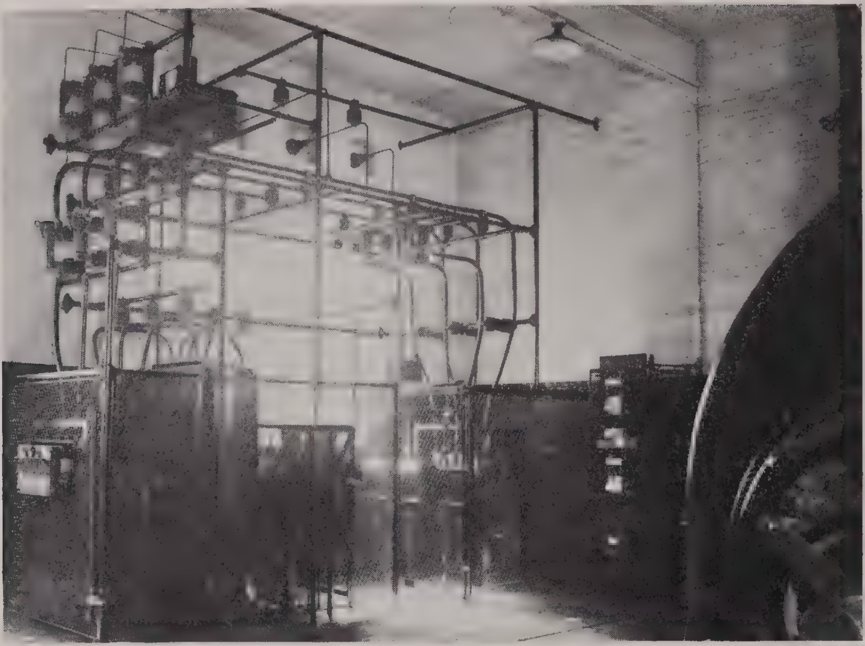

Fig. 2. Interior of the Condenser Substation Showing the Automatically Controlled Starting and Running Breakers, Compensator, and Portion of the Condenser

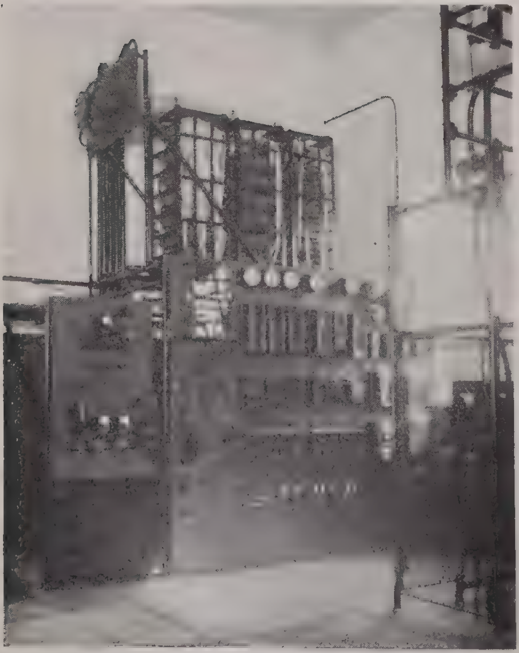

Fig. 3. Automatic Switchboard with Condenser-field Contactor Panel at the Left and Rheostat at the Top

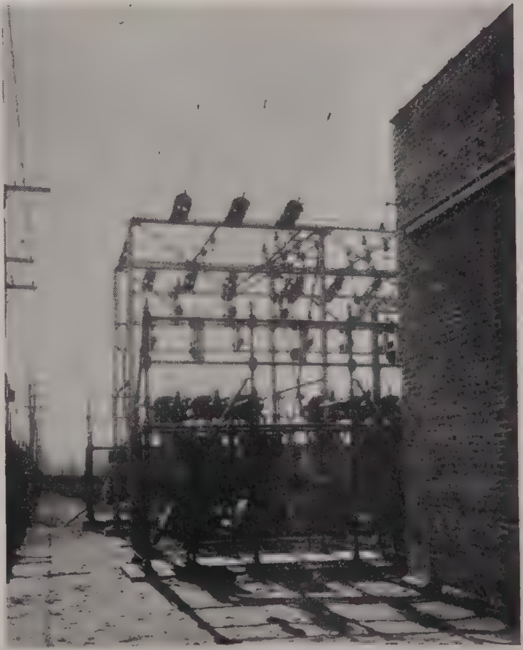

Fig. 4. A Portion of the Outdoor Switching Structure, a Full View of which from the Opposite Side is shown in Fig. 5

condenser building. The circuits were so arranged that the load and the condenser were fed from one bay, and a power and tie circuit taken from each of the other two bays. Oil circuit breakers were installed on each circuit and with the exception of the two tie circuits automatic tripping was provided. In addition to this, balanced power protection was also provided on the two power circuits. Energy for tripping was supplied by two 12-volt automobile-type storage batteries. These storage batteries are kept charged by connecting them to the condenser exciter leads through a lamp resistance. A relay in the charging circuit disconnects the battery from the exciter when the exciter voltage falls below a predetermined value. In case of automatic tripping of the oil circuit breakers, a man can be dispatched to the station to reclose them in a very short time. In the design an effort was made to make the station as simple as possible and to eliminate all equipment which normally calls for a considerable amount of attention and maintenance. For this reason a regular station battery with its accompanying charging set was omitted.

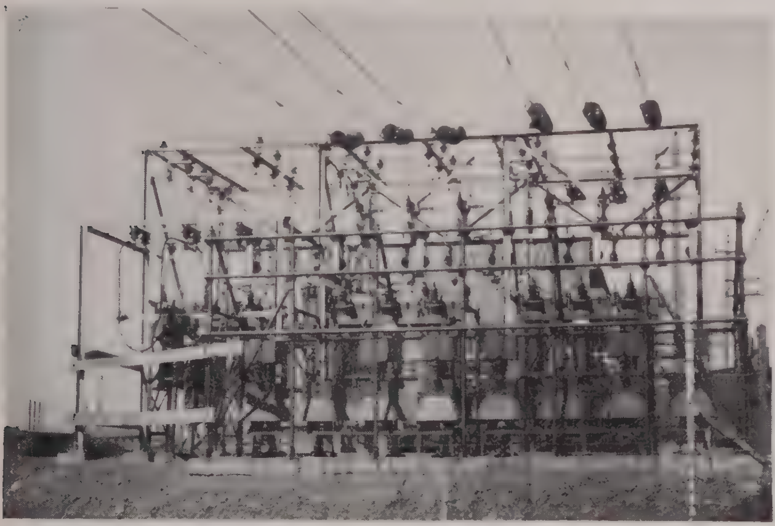

Fig. 5. Outdoor Switching Structure Showing Overhead Lines, Oil Circuit Breakers and Lightning Arresters, and the Automatic Synchronous Condenser Substation in the Background

The automatic control equipment for the condenser is so arranged by means of a time clock, and voltage relay, that if the voltage between the hours of 7 a.m. and 6 p.m. falls below 13,200, the condenser automatically starts up and boosts the voltage to about 13,800. This voltage it will maintain within the capacity of the machine until such time as the system voltage rises to a point where it automatically shuts down due to light load. Due to the fact that no battery is available for closing the switches, the starting and magnetizing switches are operated by a fly-ball mechanism driven by an alternating-current motor. Use is made of the new type of alternating-current voltage regulator which has no direct-current coil and hence gives perfect control even when the direct-current voltage is at a very low value. The machine is protected against bearing trouble, low voltage, loss of load, single-phase operation, overload, loss of field, excitation and current unbalance.

One condition which is rather severe on equipment of this sort is the low temperature which is likely to occur during the periods when the machine is not operating. The air is taken from outside through a passageway in the foundation and after cooling the machine rises through a sheet-metal duct and is then discharged through a roof ventilator. This duct has doors which can be opened and part of the warm air used for heating the building. Upon the machine shutting down at night it was noted that the intake passage, the warm machine, and the discharge air duct acted as a very good chimney and in a short time the machine lost its heat. During cold weather this resulted in a low temperature in the building before morning. To remedy this condition, there was placed in the intake duct a balanced butterfly valve which opened when the machine started and closed upon shutting down. As a further help toward eliminating cold weather difficulties, small heating elements are installed in the main bearing oil wells and so connected that they are energized when the machine is shut down. Some trouble was experienced at first with the bellows type relays on account of low temperatures but this has been remedied by substituting bellows impregnated with a different kind of oil. After eliminating the difficulties due to low temperatures the equipment functions very satisfactorily.

Automatic Stations in New England

A Survey of Electric Service Furnished Automatically—Railway and Industrial Power Conversion—Hydro-electric Power Generation—Power-factor Correction—Reclosing Feeder Distribution—Supervisory Control—Installations, Operating Conditions and Performance

By T. A. Barry
Engineering Department, Boston Office, General Electric Company

T. A. Barry

THE first automatic stations in New England were two railway substations installed by the United Electric Railways Co. of Providence in 1917. One of these was a single-unit, 60-cycle station of 300-kw. capacity; and the other a two-unit, 25-cycle station of 600-kw. capacity. The war and the following readjustment period held up further activity in the automatic field until 1920. Since that date, however, the activity and interest in automatic equipment has increased very rapidly. This is due in part to the perfecting of the art and to the experience gained in the operation of automatic equipments. However, the increasing demands for better service, coupled with the cost of meeting such demands, are playing no small part in this increasing activity. Both industries and central stations are looking to the automatic substation to help solve their problem of better service at lower cost of operation.

Railway Substations

Although a street railway company was the first to take up the automatic substation in New England, the application of automatic control to this class of service has progressed very slowly. There are some very good reasons for this, chiefly the financial problems of the street railway of today. The increasing use of the automobile and lately of the motor bus, combined with the demand for higher wages of railway employees, have made the successful operation of all of our street railways a difficult problem.

There are, however, many cases where a rehabilitation of the present equipment with the addition of automatic control would result in a material reduction in operating costs. The Androscoggin & Kennebec Ry. of Lewiston, Maine, is working out such a plan and has two full automatic and two semi-automatic substations in operation.

A complete automatic control is being built for the Boston Elevated Railway Company's Oak Square station. This station has two 2000-kw., 25-cycle synchronous converters and nine 1200-amp. direct-current feeder circuits installed. A complete supervisory equipment of the distributor type will be super-imposed on the automatic control, giving the dispatcher complete supervision of the direct-current feeders and converters.

Industrial Substations

The field for automatic control of conversion apparatus for industrial purposes is very limited in New England. We have, however, one rather unique installation: that of the Dennison Mfg. Co. at Framingham, Mass. This consists of two 330-kw., 250-volt, synchronous converters connected to the lines of the Edison Electric Illuminating Co. of Boston, operating in parallel with direct-connected engine-driven direct-current units. The parallel operation of these automatically controlled converters with the engine-driven units has been very successful, being assured by an induction regulator which controls the voltage of the alternating-current supply to the synchronous converters. (1)

Hydro-electric Stations

Natural conditions, combined with the cost and difficulty of securing reliable and efficient operators, have made the hydro-electric station the largest field of application for automatic control in New England. We have only a few large waterpowers at present undeveloped, and most of these would require a relatively high first cost. We do have, however, a great many small waterpowers which were not feasible of development until the advent of the automatic station. The increasing interconnections between systems have also made it not only desirable but profitable to develop these small powers.

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(1) A detailed description of this installation is given in the article "Automatic Synchronous Converter Equipment at the Dennison Manufacturing Co.", by W. S. Fitch, on page 398 of this issue.—(Ed.)

The first automatic hydro-electric station in New England was installed by the Holyoke Water Power Co., at Holyoke, Mass., in 1921. This consisted of a 625-kv-a., 6600-volt vertical unit installed at the Boat Lock Station, taking water from the first-level canal and discharging into the second level, thereby balancing the load on the first-level canal with that on the second level. Before the installation of this station it was often necessary to by-pass water through waste gates from the first to the second-level canal. In 1924 this station was enlarged and two 1500-kv-a. units added. These three machines are remotely controlled from the main generating station a mile away; and it is possible to stop and start the station, to raise and lower the load on each unit, and to indicate back to the main station the gate opening of each unit.

Fig. 1. Automatic Hydro-electric Station at Alton, N. H., Which Contains a 150-kv-a., 4000-volt Generating Unit

Among the plans which have been outlined for the development of the smaller waterpowers is one which merits further consideration. This is the use of automatic stations to reduce the cost of operation and very often the cost of development. Under this plan it is entirely feasible to tie together a number of such plants on one stream, and so regulate the automatic operation that full advantage can be taken of the water conditions, and at the same time keep the operating expense down to a minimum. Such a plan has been worked out and put into operation by the Geo. H. Jones Co. of Alton, N. H., in conjunction with the Twin State Gas & Electric Co. of Boston which operates and purchases the entire output of the plants. The system consists of three stations located on the Merry Meeting river. Station No. 1 with a 300-kv-a. unit operating on a 60-ft. head is located at the outlet of a large storage reservoir. Station No. 2 with a 225-kv-a. unit operating on a 50-ft. head is located approximately 2½ miles below Station No. 1 at New Durham. Station No. 3 with a 150-kv-a. unit operating on a 20-ft. head is located approximately 2 miles below Station No. 2 at Alton.

Power is generated at 4000 volts and brought direct from Stations No. 1 and 3 to No. 2 where the output of all three stations is stepped up to the 13,200-volt transmission system of the Twin State Gas & Electric Co. One operator located at Station No. 2 controls all three stations. As it was desired to draw the water from the storage reservoir at a definite and constant rate during dry periods, it was necessary to arrange the control accordingly. This was done by equipping the governor with a motor-driven gate-limit stop and running three control wires between stations. An indicating wattmeter was installed at Station No. 2 on the incoming line from Station No. 1 to indicate the load on Station No. 1, and thereby the gate opening of the wheel. Knowing the kilowatt output of the wheel for various gate openings, it is only necessary for the operator to adjust the gate-limit stop by means of the remote control to give the desired load on the station. After being so adjusted, the wheel will run at a fixed gate and consequently discharge a definite and constant amount of water.

The operation of Stations No. 2 and 3 is controlled by float switches which cut the generating units on and off the line according to water conditions.

The largest automatic hydro-electric station now in operation in New England is the Searsburg station of the New England Power

Co., in which is installed a 5000-kv-a., 2300-volt vertical generating unit.⁽²⁾

For the Farmington River Power Co., New Britain, Conn., we are building two 5000-kv-a., 2300-volt, 150-r.p.m. vertical waterwheel generators with complete automatic control. When installed, this will be the largest automatic station of its kind. The station will be located on the Farmington River approximately 17 miles from New Britain. The bulk of the power will be transmitted to the Stanley Co. for use in its shops at New Britain.

The activity in automatic hydro-electric equipments has not been confined only to the central stations. Industrial plants are also installing automatic generating stations. The American Powder Mills has a 210-kv-a., 600-volt station in operation at Maynard, Mass. The American Thread Co., of Willimantic, Conn., is installing a 625-kv-a., 2300-volt station. The Continental Paper & Bag Mills Corp., of Rumford, Me., is equipping two of its existing hydro-electric stations with automatic control. The Walter Baker Co., of Milton, Mass., has a three-unit automatic station of 375-kv-a. capacity on the Neponset River. The first water-power in the United States was developed on the site of this station by the early Colonists to grind corn and has a very interesting history.

In the New England district we have installed 16 automatic hydro-electric stations, are now installing 3 more, and are manufacturing the equipment for 2 in addition. The total generating capacity of these will be approximately 27,500 kv-a.

Synchronous Condenser Substations

This last year the New England Power Co. put into operation at Worcester, Mass., a 7500-kv-a., 13,800-volt synchronous condenser with complete automatic control.⁽³⁾

Automatic Reclosing Substations

But a few years ago most of the electric light and power systems consisted of isolated plants each supplying its own community. There were very few interconnections between systems. A great many of these isolated plants have now been discarded and the communities formerly served by them are now supplied over high-voltage transmission lines. The interconnection of systems is rapidly increasing. The increase in the use of electric power has made necessary the installation of more and more substations to take care of the service economically. To maintain attendants in many of these substations would place a heavy burden on the operating company, so great in some cases as to cancel the economies of the substation as a distributing agent and a means of rendering better service to the public. This situation has been successfully met by the automatic reclosing station.

Fig. 2. 5000-kw. Hydro-electric Plant at Searsburg, Vt., Which Operates Entirely Without Human Direction

The first reclosing substation in New England was installed at Medford, Mass., in 1921 by the Malden Electric Co., a property of the C. H. Tenney Co. The substation has a capacity of 2250 kv-a. which will shortly be increased to 4500 kv-a. It is supplied from Malden at 22,000 volts through two underground cables. Power is transformed to 2300 volts, three-phase, for general power and lighting. Street lighting is also supplied from the substation by constant-current trans-

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⁽²⁾ A description of this installation is given in the article "Full-automatic Hydro-electric Station", by E. B. Collins, *Electrical World*, May 19, 1923, Vol. 81, pp. 1143-1147.

⁽³⁾ A detailed description is given in the article "7500-kv-a. Automatic Synchronous Condenser at the South Works of the American Steel & Wire Co., Worcester, Mass.", by E. B. Collins, on page 389 of this issue.—Ed.

formers which are also automatically controlled. The performance record of this reclosing substation is interesting to note because the station was placed in service a short time before one of the worst ice and sleet storms which New England has ever experienced. Even under these exceptionally severe conditions, the operation of the reclosing equipment was 100 per cent. Not only did the switches go through their normal duty cycle of three reclosings but were put through their cycle of operation two and three times by an operator who was at the station during the storm, all without a failure.

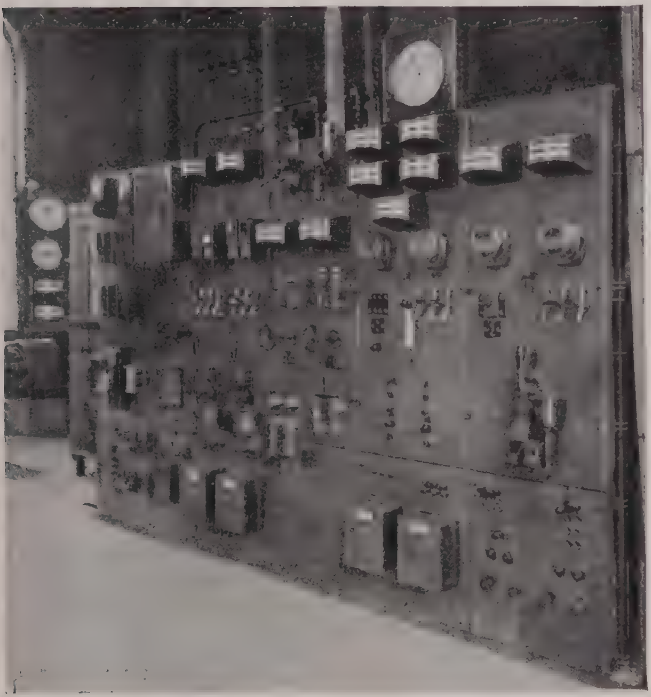


Fig. 3. Automatic Switching Equipment in the Searsburg Station

The Malden Electric Co. has a second reclosing substation in operation at Everett, Mass., of 3000-kv-a. capacity. This station is also fed from Malden at 22,000 volts. The power can be transformed to 2300 volts or to 4000 volts Y. The distribution from this station is at 2300 volts at present, but the equipment can be changed over to 4000 volts Y when service demands it. A third reclosing substation is being installed at Melrose, Mass. This will be a duplicate of the Everett substation in arrangement and equipment except that two banks of transformers instead of one will be installed. One bank, however, will carry the load of the station at present, the other bank being held as a spare. The equipment of these substations is wholly indoors. The switches and buses are mounted in concrete structures, and on the low-tension side a main and auxiliary bus is provided.

The Suburban Gas & Electric Co. of Revere, Mass., another C. H. Tenney Co. property, has an automatic-reclosing truck-type switchboard at the station in Revere. Power is received from Malden at 22,000 volts and stepped down through a bank of three 1000-kv-a. transformers to 2300 volts or to 4000 volts Y. Up to the present time the station has been operating at 2300 volts but some of the circuits will shortly be changed over to 4000-volt Y-operation. The high-tension switching and transformers at this station are outdoor. Connection is also made at this station between the Edison Electric Illuminating Co. of Boston and the 22,000-volt transmission system of the Eastern Masssachusetts Electric Co. This latter company is owned by the C. H. Tenney Co. and operates the transmission system between Salem, Mass., Malden, and the substations at Revere. Power is fed into the system from the northern end by the Salem Electric Light Co. and from the south by the Boston Edison Company.

The Blackstone Valley Gas & Electric Co., of Pawtucket, R. I., is placing in service at York Avenue a complete outdoor reclosing substation. Power will be supplied at 13,200 volts and transformed to 2300 volts for light and power. The present capacity will be 1500 kv-a. with an ultimate of 6000 kv-a. All switching equipment is installed in outdoor switch houses and operated by alternating-current motors. Two 13,200-volt, three-phase lines are brought into the station, one of which will be the "normal" source and the other the "emergency" source. The switching of these two lines is so arranged that in case of failure of power on the normal line, the station will be automatically transferred to the emergency source. As soon as normal conditions are restored on the normal line, the station will be transferred back to it. The low-tension feeder switches will be reclosing.

This same company will install a second substation this summer similar to the York

Fig. 4. Medford Substation of the Malden Electric Co.

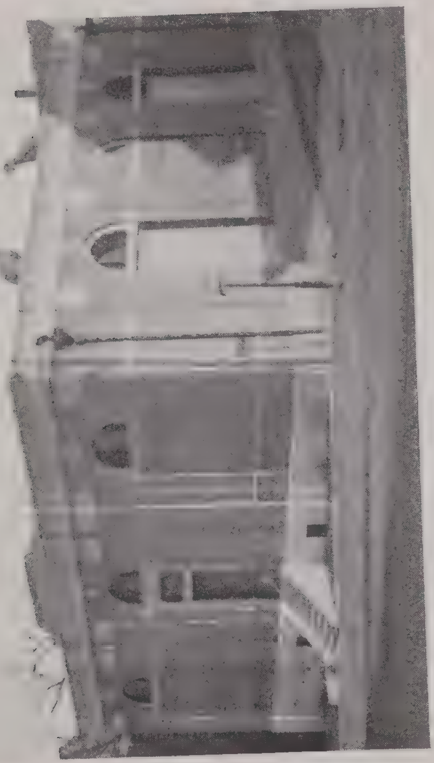


Fig. 5. Automatic Substation at Everett, Mass.

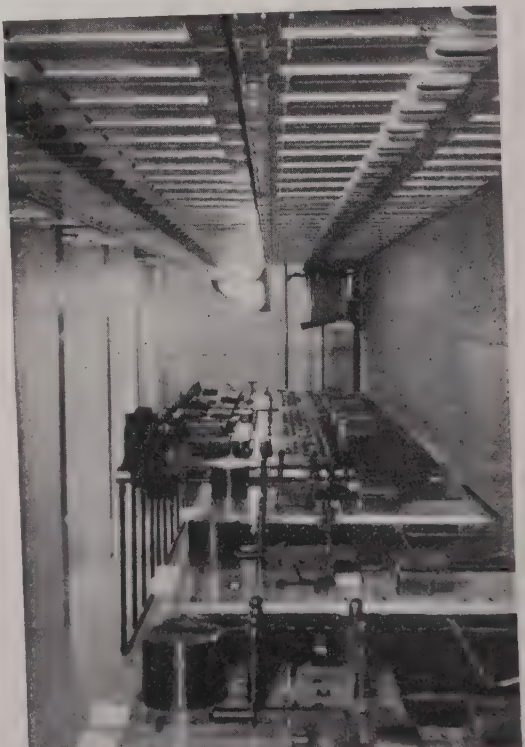


Fig. 6. Switchboard and Low-tension Bus Structure, Everett Substation

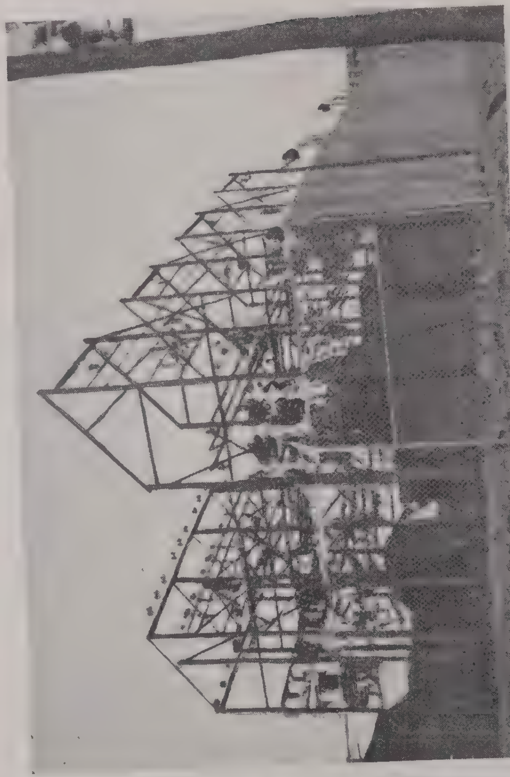


Fig. 7. Outdoor Automatic Equipment, York Ave. Substation of the Blackstone Valley Gas & Electric Company

Avenue station. The 13,200-volt switching equipment at the new station will be installed out of doors in switch houses and the low-tension switches indoors. All switches will be solenoid operated. The general scheme of operation, however, will be the same as that of the York Avenue station. It is also proposed to install constant-current transformers to take care of street lighting from this station.

A case which illustrates the adaptability of the reclosing substation to improve service is that of the Swampscott Station of the Lynn Gas & Electric Co. of Lynn. This company supplies the power and lighting demands of the town of Swampscott which is almost entirely a residential district. A 4000-volt feeder is run underground from the main station to Swampscott where it is tapped to several overhead circuits. Inasmuch as the town authorities will allow no tree trimming, it was a very difficult problem to keep down the number of interruptions. Last summer the Lynn Gas & Electric Co. was faced with the problem of either putting their lines underground in this section or of installing additional feeder circuits from the main station which would have required the construction of new duct lines. In either case, the first cost would have been entirely out of proportion to the revenue received. To save this large investment, a reclosing substation is being installed which will break up into four sections the area now served by one feeder. With this arrangement, trouble occurring in one section will be localized and will not affect the other sections.

Many other reclosing substations are in operation or being installed in New England, but space does not permit of a description of each one. Reclosing stations for 13,200-volt and 22,000-volt feeders are being installed. A majority of the stations are of the indoor type but the tendency is more and more toward outdoor installations. Especially is this true of the smaller stations where the outdoor switch house has a decided advantage in first cost.

Supervisory Control Equipment

The largest installation of supervisory control which we have in New England is that of the Malden Electric Co. This is also believed to be the first extensive supervisory system to be installed in the world for the control and indication of power equipment. It is of the distributor type. The dispatcher's station is located at Malden from which all switches in the Medford, Everett, and Melrose stations are supervised. Provision has also been made for the control of the Revere Station. In all substations, transfer switches are provided whereby the main oil circuit breakers may be controlled either directly over the supervisory system or by the reclosing relays. The positions of the oil circuit breakers, however, are indicated at all times to the dispatcher at Malden.

We have two installations of the selector type of control in operation. The United Electric Light Co., of Springfield, Mass., has installed this type between its main generating station and Substation No. 5 where twelve oil circuit breakers are supervised. The Edison Electric Illuminating Co. supervises the operation of three oil circuit breakers in the West Medway Substation from the Hopkinton Substation.

A third installation of the selector type will soon be put in service by the United Electric Rys. Co. of Providence. Eight 11,000-volt outdoor oil circuit breakers at the Lincoln Substation will be controlled from the No. Main St. Substation.

The Connecticut Power Co., of New London, Conn., has a cable and polarized relay system in operation at Middletown, Conn. Three 66,000-volt oil circuit breakers at the stepdown transformer station outside of the city are controlled from the distributing station over a distance of three miles.

The Narragansett Electric Light Co., of Providence, R. I., also has installed this type of control at its Elmwood Substation.

There are two installations of the balanced-resistance type of control in operation in the New England district. The operation of the automatic hydro-electric station of the Holyoke Water Power Co., previously mentioned, is controlled by this method from the main generating station approximately one mile away. The Winchendon Light & Power Co. is also controlling the operation of an automatic hydro-electric unit over approximately the same distance. This control enables the operator at the main station to stop and start each generator, raise and lower the load on any generator, and also receive back a continuous indication of the gate opening of each waterwheel.

Automatic Synchronous Converter Equipment at the Dennison Manufacturing Company

An Industrial Installation of Automatic Equipment—Transforms and Converts Purchased Power—Supplements Generated Power—Installed as Best Means of Increasing Power Supply—Two Converting Equipments—Starting and Stopping Functions Initiated by Power-house Operator—Exhaust Steam No Longer in Excess of Process and Heating Needs

By W. S. Fitch

Construction Engineer, Dennison Manufacturing Company

W. S. Fitch

During 1898 the factory of the Dennison Manufacturing Company was moved from Roxbury, Mass., to Framingham, Mass., where the plant formerly owned by the Para Rubber Company had been remodeled, enlarged, and equipped with what was then considered a modern electric system for power and lighting, using 115 volts direct current.

As the factory developed, no additional motors for group drives were added but motors of the variable-speed type were installed on individual machines. By 1910 the electric and steam loads had so increased that a new power plant had to be built in a new location.

In this power plant 250-volt, 2-wire direct-current generators were installed with balancers to operate 115-volt lamps and 115-volt motors of the smaller sizes, 230-volt motors having been substituted for the larger 115-volt motors. All the new motor equipment was for operation on 230 volts.

Conditions in 1921

Due to additional factory buildings and increased power and lighting equipment, the peak load in 1921 called for the operation of all of the available generating units. The growth in power and lighting requirements had been greater than the increased requirements for process steam, so that year by year the amount of steam exhausted to the atmosphere gradually increased. It was felt that the time had arrived for additional generating equipment. For the existing generating units and other steam demands, the boiler room was still adequate as only three of the four boilers had to be operated during the winter and two boilers during the summer, giving at all times one spare unit to shut down for repairs and cleaning.

The Problem in 1921

The boiler plant is essentially a heating plant, supplying steam for processes and heating the buildings, either through reducing valves, or through the engines, exhausting against three pounds back pressure. This means that a large part of the power is produced at a very low rate, this power demand being relatively steady throughout the year. During the summer considerable exhaust steam is wasted to the atmosphere; and during the winter months, especially when lighting peaks come on days when the weather is moderate, a large amount of exhaust steam is wasted. Records indicated that the current produced by the three generators, having a total capacity of 850 kw., amounted to about 1,500,000 kw-hr. per year, and that nearly half the steam or that used to produce 700,000 kw-hr. per year is wasted to the atmosphere. As the three main generating units (direct-connected to Corliss engines taking steam at 140 lb.) are loaded to capacity during lighting peak periods, additional generating equipment is needed, and to comply with past practice a reasonable reserve capacity should be provided. At the same time it is highly desirable to make the installation in such a way as to improve the overall operating efficiency of the plant.

Solution of Problem

About twenty different plans, including gas engines; Diesel engines; condensing engines; non-condensing engines; condensing turbines; non-condensing turbines; uniflow engines;

bleeder-type turbines; motor-generator sets; and synchronous converters with transformers, were studied; and estimates of the cost of installation, yearly charges on investment, operating costs, and total yearly charges were tabulated. In the early stages of this study, it was felt that if outside purchased power were to be used the only suitable equipment would be a motor-generator set with its comparatively low efficiency. No condensing water being available at the site of the power plant, the installation of a 500-kw. condensing turbine, direct-connected to a 250-volt direct-current generator with necessary condensers, and cooling pond for the condenser water, was carefully considered.

If a spare boiler unit were to be maintained, this plan would call for investment in a new boiler, and would therefore increase considerably the initial investment and slightly increase the annual charges as compared with synchronous converter equipment to operate on purchased power.

As none of the plans investigated indicated any large amount of saving in yearly charges, including initial investment, operating costs, and fixed charges, it was found that other items would be the determining factors. Synchronous converter equipment was finally selected because its initial investment was less, its reliability of operation was considered equal and its operating simplicity greater than the corresponding factors with a condensing turbine, and the necessary reduction gears of a turbine drive were not considered especially desirable. General desirability was really a large determining factor.

It was felt that purchased power would make possible the meeting of future conditions with a free hand, and advantage could later be taken of improvements and developments in power generating equipment. It would be comparatively easy to change from purchased power to owners' generating equipment at a future date, and the salvage value of the converter equipment would be fairly high. It developed that there was some question as to whether a synchronous converter in the 300-kw. size would be an acceptable load for purchased power. It was later found that this equipment was acceptable, in consequence of which it was decided to build a new transformer house having a capacity of about 600-kw. in service equipment and to install at present transformers and switching facilities for a single converter of approximately 300-kw. capacity.

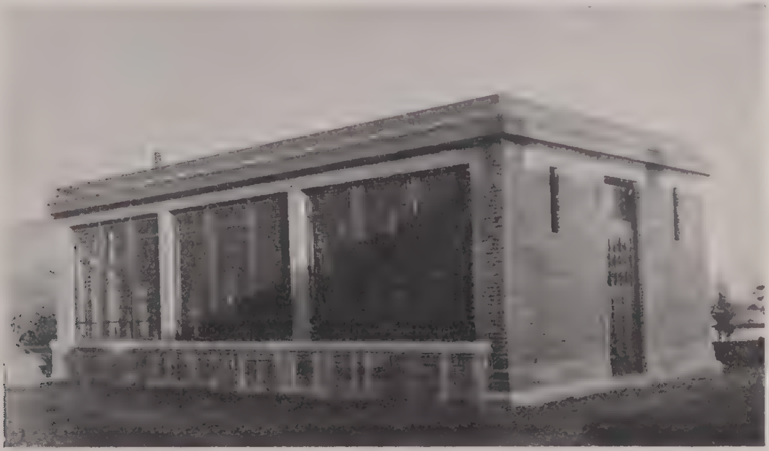


Fig. 1. Transformer House of the Dennison Mfg. Co. at Framingham, Mass., Built to Supply Power for Automatic Equipment Recently Installed in the Power House

Equipment Installed in 1922

Fig. 1 shows the exterior of the transformer house designed for this equipment. Underground, 3-phase, 13,200-volt conductors are looped into this building. Through disconnecting switches and oil circuit breakers, current is supplied to the buses and from these buses to disconnecting switches and oil circuit breakers, which are remote-controlled by switches on the main switchboard in the engine room. The bank of transformers in the right-hand panel of the transformer platform, Fig. 1, delivers 440-volt 3-phase current to an air compressor motor in the engine room and through another transformer supplies current for emergency lighting at 110 volts alternating-current in the power house. Through another circuit breaker, current is supplied to an induction voltage regulator of 600-kw. capacity. Through a bank of three transformers located in the center panel, 6-phase, 185-volt, 60-cycle current is supplied to the 330-kw., 250-volt synchronous converter.

The panel at the left allows for future installation of duplicate equipment.

The first converter unit was put into service the latter part of 1922.

Apparatus, Including Automatic Equipment

Fig. 2 shows the two synchronous converters and their location in relation to the engine units, the flywheel of one engine unit being seen in the background. This view was taken looking toward the end of the engine room where the switchboard is located.

Fig. 3 shows the three panels added to the original switchboard for controlling the operation of the two synchronous converters. The strip recording instrument at the center of the right-hand panel shows the total load being carried on purchased current, including the 440-volt motor on the air compressor drive. The strip recording instrument on the lower part of the left-hand panel records the high-tension voltage on the outside lines. The two wattmeters on the center panel at the bottom record respectively the total output of the two converters. The recording wattmeter at the bottom of the right-hand panel records the total current purchased. The single-pole circuit breakers and three-pole knife switches on the two left-hand panels are used for connecting the two converters for parallel operation on the common buses with the engine-driven units.

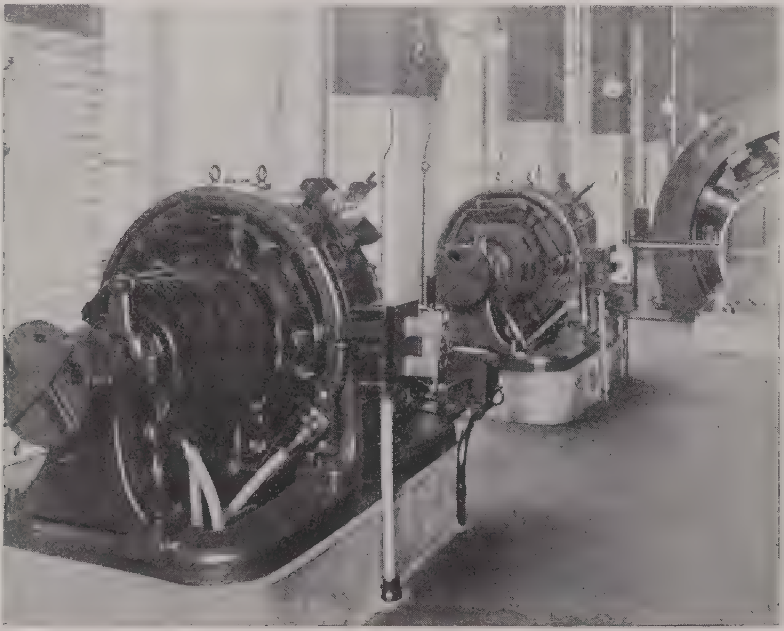


Fig. 2. Two Automatically Controlled Synchronous Converters in the Main Power House of the Dennison Company

Conditions in 1924

Due to increase in motor load, and also in lighting load caused by the installation in many places of larger lamps to meet the demand for improved illumination, the capacity of the converter was largely absorbed so that not more than 150-kw. spare plant capacity was available. Early in 1924 steps were therefore taken to install a second converter unit, provision for which had been made throughout in the original installation. During July the converter was delivered and work begun on the installation of the necessary wiring and switching equipment, the installation being completed and ready for operation in November, 1924.

Between the two large instruments on the right-hand panel are shown the indicating switches for controlling the oil circuit breakers in the transformer house. There are four such switches, the center one in the illustration being a blank.

Fig. 4 shows the two automatic control switchboards mounted on the floor directly under the two converters. The three-panel switchboard at the left controls the 440-volt circuit for power, and 110-volt circuit for emergency power-house lighting.

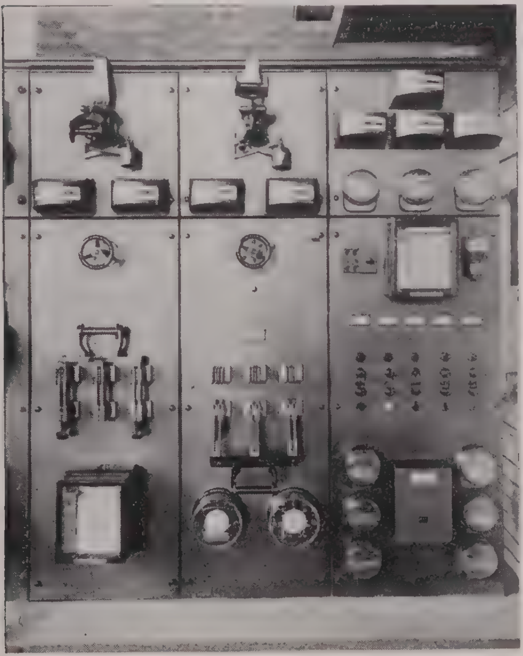


Fig. 3. Metering and Remote Control Panels in Main Power House

Fig. 5 is a view in back of the automatic switchboard looking toward the transformer house from which the lower cables in the center of the illustration are run in conduit underground. The vertical cables at the left connect the switchboard to the synchronous converter directly overhead. The overhead cables at the right run from the switchboards and converters to the main switchboard. The resistance shown at the right is a load-limiting resistance and is equipped with thermostats for limiting the time that the resistance can remain in service.

The small motor-generator at the right is used for flashing the fields when starting up either of the two converters.

Automatic Control of Equipment

In a manually operated synchronous converter equipment, the station attendant has several operations to perform in starting up and in shutting down. In this plant these operations are performed automatically, and in the proper sequence by the automatic control equipment. Provision is also made against alternating-current low voltage, overheated machine windings, field failure, wrong brush position, underspeed, alternating-current or direct-current overload, hot bearings, overspeed, reverse power, single-phase running, and single-phase starting. There is an interlocking circuit between the two units so that both cannot start at the same time.

When the operator wishes to start up one of the converters, he proceeds as follows: With the disconnecting switches in the transformer house closed, he closes the oil circuit breaker through the remote control switch on the right-hand panel of the switchboard. The manually operated, single-pole, direct-current circuit breaker is next closed, which energizes the undervoltage relay, and starts the series of steps that must be carried out in the correct sequence in order to bring the machine up to the proper condition for paralleling with the other units. Necessary interlocks are provided to insure the proper sequence of steps in starting. A protective relay is energized, which prevents both converters from drawing starting current at the same time, and also shuts down the converter if it is not connected to full alternating-current voltage within a predetermined time. When shut down, the brushes on the converter, with the exception of two pilot brushes, are all raised off the commutator by means of a brush-raising motor.

After the starting contactor is closed, the synchronous speed control is energized, and the converter as it comes up to speed develops direct-current voltage and operates a relay. A contactor flashes the field of the converter and full field is soon applied. When the field current reaches about 50 per cent normal, the starting contactor is dropped out, and the running contactor closes, giving the converter full alternating-current voltage. The brush-operating motor is then energized and the brushes are lowered on the commutator. At this point the operator, having switched the station voltmeter to indicate the voltage on the converter leads, compares this with the voltage on the station buses, and when he finds it correct, closes the three-pole knife switch, thus connecting the converter to the station buses. The circuit is not completed, however, until the direct-current voltage on the converter rises slightly above the station bus voltage, at which time, through a relay, the main direct-current line contactor is closed thus connecting the converter to the load, but with the load-limiting resistance in series. Provided the converter would not be overloaded if directly on the line, three resistor-short-circuiting contactors close in succession and short-circuit the load-limiting resistance.

The equipment is now carrying its share of the load, and continues to do so unless overloaded in which case the resistors will be cut into the line again through the opening of the direct-current overload relays. As mentioned elsewhere, there are thermostats in connection with the load-limiting resistance, which will operate to shut down the equipment if an overload is carried for any considerable time.

In this plant, as there is always an attendant in the station, it has been found advisable to give him warning through a gong when these resistors operate through overload. In this way the operator has time to take the necessary steps to get another unit on the line, or readjust the distribution of load between the various units already in operation.

In shutting down by hand, the single-pole circuit breaker is tripped open, and all devices assume the "off" position. The same thing occurs in case of a severe direct-current overload sufficient to trip the single-pole circuit breaker.

From the foregoing it will be seen that, while this equipment is designed for full automatic operation, it is not quite fully automatic in this case. It will also be seen, however, that the operator has very few moves to make to get a converter started up and ready to take its share of the load. As compared with the starting up of an engine unit, it is simpler and takes less time.

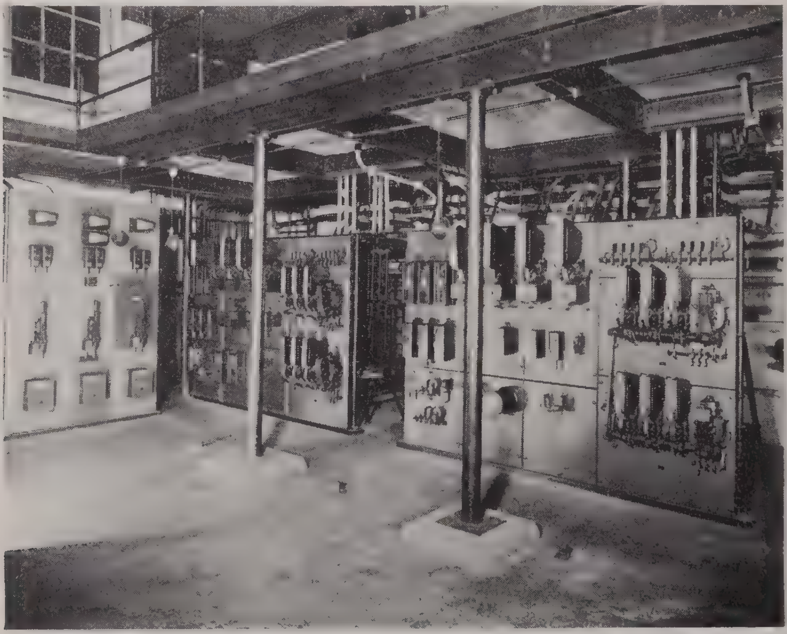


Fig. 4. Automatic Switching Equipment for the Two Synchronous Converters. The machines are located on the floor above

Results Obtained

During the 13 years of operation of this isolated plant, there have been comparatively few times when the entire equipment has been shut down during working hours. The causes for shut-downs have included careless manipulation by electricians in making changes on switchboards, the loss of steam pressure on the boilers through poor fuel or possibly attempting to operate with one less boiler than the conditions demanded, and also a sudden increase in load due to storm conditions. Soon after the first converter was put in service, trouble due to shut-downs of the plant developed, due to momentary or continued drop in voltage on the high-tension lines. Such failure of voltage has been due largely to underground cable faults, and assurance has been given that by installing improved switching equipment, which will more quickly isolate cables which are at fault, less disturbance to the system in general will occur in the future.

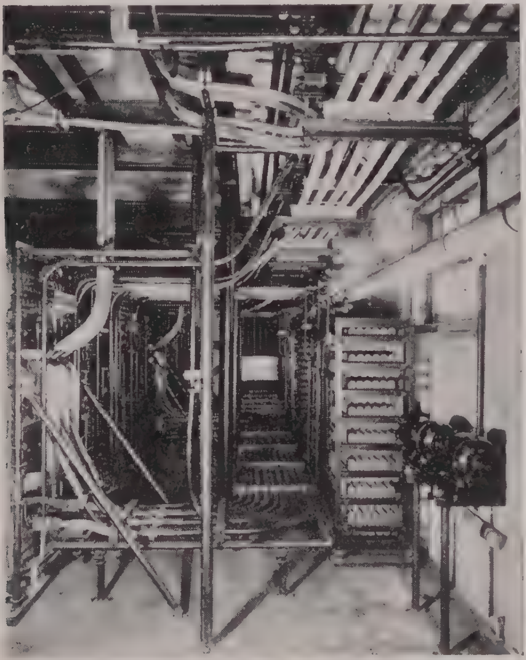


Fig. 5. A Rear View of the Automatic Switching Equipment Shown in Fig. 4

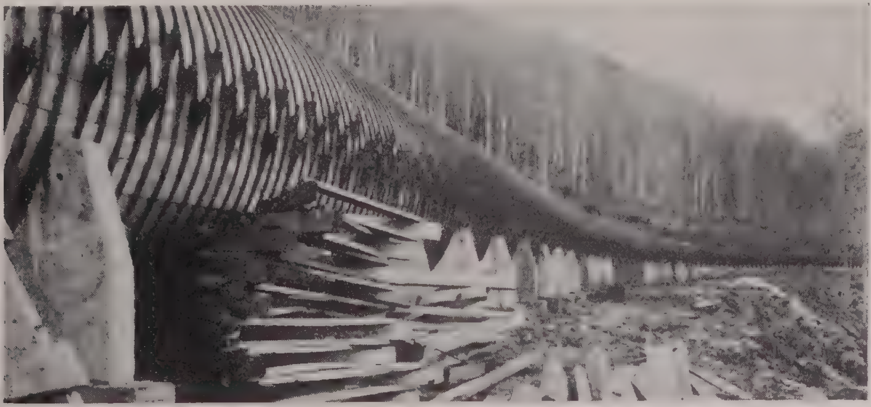
As this is possibly the first installation of its kind, there have of course been some operating conditions which have had to be corrected from time to time.

Conclusions

During summer conditions in 1924 and also during the period of lighting peak in the winter months, it was found that with the single converter there was not capacity enough to eliminate entirely the waste of exhaust steam to the atmosphere. Under present operating conditions with the two machines, the plant should be able to operate normally under any conditions without wasting exhaust steam.

While under some conditions this may not indicate the most economical production of power, there is some value from the psychological standpoint to be able to operate under practically any conditions without the waste of exhaust steam.

As the power and lighting demands increase in the future, it will again become necessary to face the problem as to the best source for additional power. The present belief is that it will not be to purchase additional outside power, but will probably lead to the installation of more economical steam units in place of the present engines, or possibly the adoption of a prime mover of an entirely different type. In other words, the feeling at this time is that too much dependance should not be put on an outside source of power, either from a reliability standpoint or from the standpoint of economical production of power.

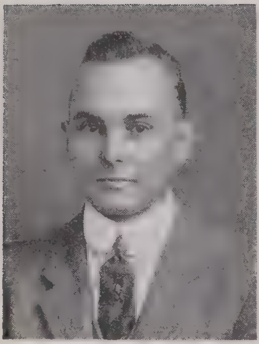


Wood-stave Penstock Which Carries the Water to the Searsburg Automatic Hydro-electric Station Shown on the Cover of This Issue

Automatic Substations for Industrial Service

Influence of Load Demand on Availability of Power Supply—Production Factors Additional to Economy of Service—Two Classifications of Industrial Distribution—Requirements of Each Fulfilled by Automatic Equipment—Protection—Power-factor—Typical Synchronous-converter and Motor-generator Installations

By C. E. H. von Sothen
Industrial Engineering Department, General Electric Company


C. E. H. von Sothen

DURING the past few years, considerable interest has been manifested by engineers associated with industrial plants in the possibilities offered by the automatic operation of motor-generator and synchronous-converter substations. This interest has been inspired chiefly by the success of the automatic substation in other fields, and has been stimulated by the increase in wages together with the difficulty in many cases of obtaining competent operators.

There are of course several different methods of starting and stopping an automatic substation, but it is quite commonly agreed that for industrial service it is advisable to use some method other than starting on low direct-current voltage and shutting down on prolonged lack of load. In most industrial plants, the load increases so rapidly that a set starting on load demand cannot get on the line in time to be of assistance. For this reason it is better to use a remote control switch to start the machine sufficiently in advance, so that it may be ready when the demand is placed upon it. The machine may also be started by switching the alternating-current feeder supplying the station.

An interesting installation of small capacity is that of the Dennison Manufacturing Company at Framingham, Mass. The original installation at this plant consisted of two 350-kw. and one 150-kw., 250-volt engine-driven generators. Growth of the plant made it necessary in 1922 to install additional generating capacity. As sufficient exhaust steam for heating and certain manufacturing processes could be obtained from the engines already in operation, it was decided to purchase power from the Edison Illuminating Company of Boston. Various types of converting apparatus and control were investigated with the result that the management decided to purchase a 330-kw., 250-volt synchronous converter with control that is completely automatic in operation. An induction regulator was installed to compensate for any variations in incoming voltage so as to simplify parallel operation of the converter and engine-driven machines.

Further growth of the plant necessitated the installation last year of a duplicate converter equipment. These machines are located at the far end of the engine room, with their control panels in the basement directly underneath. The operator can start either machine by means of a small control switch on the main board. The machine control is of the type generally used in mining and industrial automatic stations and automatically starts the machine and builds up the voltage preparatory to connecting it to the station bus. The operator then parallels the converter and engine machines and keeps the load properly balanced between them. As the engine-driven machines drop their voltage considerably on overloads, load-limiting resistors were installed between the converters and the bus to prevent these machines from assuming all load peaks. This resistance is automatically cut in by contactors when the load reaches a predetermined value.

Automatic control for these machines was installed principally to relieve the operator and protect the machines. The operator is kept quite busy regulating the pressure and quantity of process steam by varying the load on the engine-driven machines. Because of the location of the converters, he would have difficulty in starting them and giving them proper attention, especially in the case of failure and return of power.(1)

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(1) A more complete description of this particular substation is given in the article, "Automatic Synchronous Converter Equipment at the Dennison Manufacturing Co." by W. S. Fitch, page 398.—(Ed.)

Good electrical operation in industry is of vastly greater importance than is indicated by the percentage cost of energy to total manufacturing cost, or even by the percentage cost of maintaining the entire electrical department, since the output of most manufacturing operations is almost completely dependent on adequate electric service. A general interruption of electric service to an industrial plant causes a loss of production which lasts not only during the interruption but in many cases after the restoration of service while the various interrelated operations are being resumed. Spoilage of material in process of manufacture or damage to appliances may be serious additional elements of loss.

It follows, therefore, that reliability of electrical service is of prime importance and the design of control equipments for industrial automatic substations should call for the elimination of all refinements except those which improve the electric service maintained at the various parts of the plant.

Many industrial plants, notably steel mills, have expanded so extensively within the past few years that they now cover very large areas. The supply of electric power to the various parts of these plants has therefore become a problem of considerable magnitude and every possible precaution must be taken to maintain satisfactory service. Such plants may be divided into two general classes. The first consists of those in which several substations are located about the plant, with their direct-current sides tied-in to form a network. All loads are tapped off this network. The second and larger class contains those plants in which the loads are concentrated within several areas so that each section may be supplied by its own substation. Only emergency lines of comparatively small capacity tie these substations together.

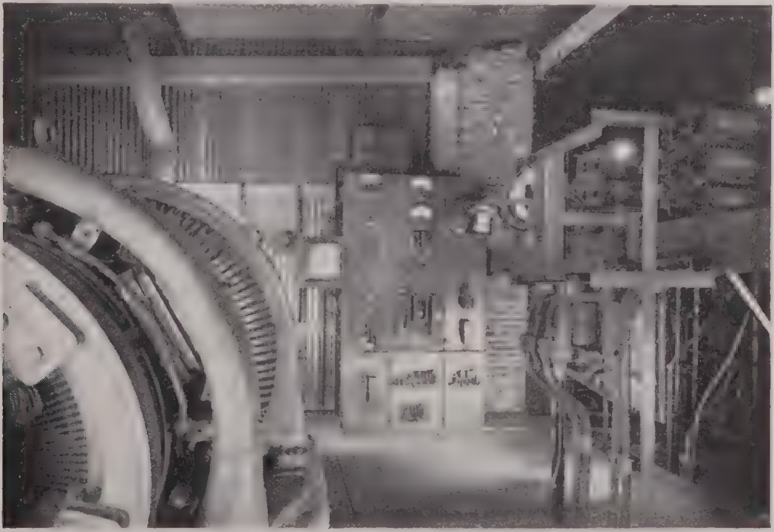

Fig. 1. Automatic Switching Equipment of the La Clede Steel Company Installed at Alton, Ill. This 250-volt, 500-kw., d-c. motor-generator set and control apparatus was one of the earliest applications of automatic equipments for industrial service

The direct-current systems of those plants which fall in "Class I" are similar to those of cities and electric railways so that the same general type of control may be used. With this system it is possible to make a station carry load up to its maximum capacity and shift only the excess to other stations. In this way, circuit breakers are prevented from tripping on overload, thus obtaining greater continuity of service. To shift load to another station requires that the voltage of the overloaded station be reduced by the insertion of load-limiting resistance or some other means. One design utilizes a differentially-compounded generator, the series field of which is normally bridged by a circuit breaker or contactor which shunts out the greater part of the series-field current. In case of overload or short circuit, the breaker is opened and the series field permitted to act differentially. On short circuit, the generator becomes a constant-current machine with its terminal voltage inversely proportional to the current flow. In case of reverse current, the generator becomes a compound-wound motor and overspeed is thus prevented. When the abnormal conditions are removed, the circuit breaker recloses and the generator once more acts practically as a shunt-wound machine.

Another type of control of this nature has been perfected for use where the power increments are large and rapid. This design uses a shunt generator provided with an exciter and a counter-electromotive force set. The armature of the counter-electromotive force set is connected in the field circuit of the main generator. Its field circuit is then varied to meet any predetermined set of conditions. Quite often the main direct-current generator is arranged to maintain practically constant terminal voltage under a load up to about 150 per cent normal. Beyond this point, the terminal voltage is decreased inversely as the current demand increases, so that in effect the machine becomes a constant-current machine beyond 150 per cent normal current. Momentary currents of three times normal and twice reversal may be safely controlled.

In applying voltage control to a substation, the type of load must be given careful consideration. If the fluctuations in load are extremely rapid, as they are in a steel mill, the voltage control device must operate practically instantly. This eliminates the motor- or solenoid-operated generator-field rheostat as a means of load regulation for such stations because of the comparatively slow operation of this type of regulation.

Most steel mills are of the type which has been designated as "Class II" plants. It is evident that no form of load-shifting control will be of assistance in such cases, since the tie-lines are not of sufficient capacity to carry any appreciable load. It must also be borne in mind that to limit the load on a station, by shifting the excess to another station operating in multiple, necessitates the lowering of the voltage of the overloaded station by some method such as those described. As most of the direct-current feeders in these plants are stub-end, i.e. fed by only one direct-current source, a lowering of the station bus voltage results in a similar decrease in voltage at the load. This slows up all operations and merely prolongs the overload. In steel mills the 250-volt distribution system is used principally for auxiliary motors most of which are of the series type or have only a very small per cent of shunt winding. As the load is of a constant-torque nature, lowering the voltage does nothing but lower the speed; the current remains the same, so that the overload is not removed from the substation.

Since the combined useful load on the feeders may at times exceed the connected generator capacity, each generator is provided with an overload relay set at the guaranteed commutating limit. These relays will open a sufficient number of feeders to relieve the generator; and after normal conditions return, the feeder circuit breakers automatically reclose. In order to protect against prolonged overloads below the setting of the generator relay, thermal protection is provided. This is usually placed in the motor circuit and consists of relays with a heating characteristic similar to that of the motor, but set to trip before the machine reaches a dangerous temperature.

An automatic equipment now being built for the Ford Motor Company will have for its principal load a 4500-h.p. motor driving a 14-in. merchant mill. The station will contain four 2000-kw., 250-volt synchronous motor-generators, one of which will tie-in with the 250-volt bus and carry the mill auxiliaries as well as excite the other machines. Two of the remaining three machines will be connected in series to supply the 500-volt main mill motor. The motor-generators and switchboard will be located in the main motor room and the starting, stopping, and regulating will be done by the switchboard operator on signals from the mill operator. The first set will be started by means of a pull-button, and then any two of the remaining sets by the proper control switch. The sets will automatically start, their motor fields will be excited, and the motors then connected to full alternating-current voltage. The operator will then pull the "Start" button for the main mill motor. This automatically puts full field on this motor, closes the breakers connecting the generators to the motor, and builds up the fields of the generators. The main mill motor will then start and accelerate as the generator voltage increases. It will come up to a speed corresponding to the previous setting of its field rheostat, contactors automatically opening in succession to insert whatever resistance was left cut in.

Normally, the main mill motor will run at constant speed, the particular speed depending upon the product being rolled. Motor-operated field rheostats will be used for both the main mill motor and the generator fields. The motor may be run from its maximum forward speed of 110 r.p.m. with weakened field, to its full-field speed of 67.5 r.p.m. in the reverse direction. Reversing, however, will be done only in an emergency and the motor-field rheostat will automatically run to the full-field position before the motor can reverse.

The automatic control equipments for motor-generators and synchronous converters in industrial service are the same as those for mining substations in so far as starting sequence is concerned. As these equipments are fully described in another article in this issue, it will be unnecessary to go into detail here.(2) The sequence in each case is the same as that considered best practice in manual operation. For example: A synchronous motor-generator is started by connecting the motor to the source of power, either through a compensator or to taps on the transformer, or through the transformers direct if Y-delta starting is used. At synchronous speed, the motor field is disconnected from its discharge resistor and connected to the exciting source. When the field current has built up to about half-normal value, the starting connection is opened and running connection made, placing full voltage on the motor. The generator voltage is then balanced with that of the bus, and when these agree the generator is connected to the bus.

Similarly, synchronous converters are usually started from half-voltage taps on the power transformers. When synchronous speed is reached, the converter field is flashed from a small exciter set to establish correct polarity. The machine is then made self-excited and at about half-normal field current the change-over from starting connection to full secondary voltage is made. The brushes are next lowered on the commutator and the machine balanced on the bus.

All of these equipments include protection against: (1) Severe alternating-current or direct-current overload, (2) failure to complete the starting sequence, (3) loss of excitation, (4) single-phase starting and under-voltage on the incoming line, (5) overheated bearings, (6) overheated machine windings, (7) temporary drop in the incoming voltage, (8) wrong polarity, (9) overspeed, and (10) reverse power.

The protective features are of two kinds: automatic reset, and hand reset. If the trouble is likely to be of a temporary nature such as overheated machine windings, low alternating-current voltage, or overload on the direct-current side, a device is used which will automatically reset when conditions return to normal. If the trouble is likely to be of a permanent nature or such that the station should be inspected or repairs made before service is restored, a hand-reset device is used to provide protection. Examples of this kind of trouble are overheated bearings, loss of excitation, and failure to complete the starting sequence.

Quite frequently an industry is able to receive a better power rate if it can raise its power-factor to some stipulated value. However, if it becomes necessary to add an operator to attend to the synchronous condenser required, much if not all of the saving is lost. Here then is an opportunity to apply automatic control to advantage. These machines are very easily controlled automatically, the equipment being practically identical with that for the motor end of a synchronous motor-generator. In addition to the usual starting and protective devices, a power-factor regulator or a voltage regulator which forms part of the automatic switching equipment adjusts the field current automatically to maintain either constant power-factor or constant voltage within the limits of operation of the unit.

Circuit breakers for both direct-current and alternating-current feeders can now readily be made automatic reclosing. The use of a load-indicating resistance in connection with such direct-current breakers has resulted in the elimination of unnecessary abuse of equipment and minimizing interruptions to service. Motor mechanisms have been perfected for oil circuit breakers, which require but a very small current for their operation, and such equipments with the necessary overload and reclosing relays have done much to improve service on alternating-current lines.

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(2) This refers to the article, "Automatic Substations in the Mining Industry," by E. L. Hough, page. 415.—(Ed.)

Automatic Substations of the Appalachian Power Company

Experience with Automatic Substations Serving a Coal Mining District—Electrical Survey of Supply and Load—Economic Allowable Increase in Capital Cost of Automatic Over Manual Equipment—Design and Operation of Substations—Inspection and Maintenance Program

By G. L. Furr *and* W. L. Webb
Appalachian Power Company

G. L. Furr

THE Appalachian Power Company operates in southern West Virginia and southwest Virginia. The West Virginia territory consists essentially of a coal mining load in the Pocahontas and Virginian coal fields. In this territory power is furnished to over 170 mines, and of this number direct-current power is supplied to 12 different operations(1), being delivered at 275 and 550 volts by synchronous converters and motor-generator sets.

Characteristics of the Load

To show the characteristics of a direct-current mine load, typical curves are given in Fig. 1 and Fig. 2. Fig. 1 is an actual curve taken from a direct-current recording ammeter on a mining load from 10 a.m. to 2 p.m. Fig. 2 gives the hourly energy consumption for the same day. The night load of this mine is higher than the average because electric cutting machines and other electrical mining machinery are used. The ordinary mine load consists of electric locomotives, of loading and cutting machinery, and of pumps, fans, hoists, and tipple motors which latter may be of either the alternating-current or direct-current type. Practically all of the hauling is done during the day. The fans when run at night are operated at reduced speed and consequently reduced load. The pumps are run mostly during the day but sometimes at night, depending upon the water conditions in the mines. The tipples and loading machines are run only during the day. The cutting machines and a few locomotives are used at night. The ammeter curve shows the rapid and irregular fluctuations of a mine load. This irregularity of load is one of the reasons why it is not satisfactory to permit direct-current machines to come on the line on load demand. The hourly consumption curve shows that there is not as much machine capacity needed at night as during the day. In order to take advantage of this it is advantageous, in a great many cases, to install two small machines to carry the load rather than one large machine. With this arrangement one of the machines carries the night load, thus saving the transformer and machine losses of the second unit. It is also very important that uninterrupted service be maintained to the fans and pumps, and with a two-unit station sufficient power for this purpose can be furnished by one of the machines in the event of failure of the other. Another advantage of two units over one large unit is that the machines may be placed in different locations, thereby lessening the direct-current transmission losses. This plan can generally be worked out so that one of the units may still be shut down at night.

W. L. Webb

Territory Served

Fig. 3 shows the geographical location of the converting stations and gives the type and capacity of the machines. The mining districts are rough and mountainous and some of the converting substations are almost inaccessible. Other of these stations are located near improved roads and can be reached by automobile in one or two hours from Bluefield, W. Va., where the main offices of the Company are situated. In general, the more nearly inaccessible locations are considered ideal for automatic equipment. This is true from an operating standpoint because satisfactory attendants for these locations are difficult to secure. Ambitious operators soon become restless and discontented and, as a result, inexperienced men had to be used before automatic equipments were installed. The Company felt that it was better to depend on these equipments than on second-class operators. However, long and unavoidable interruptions of power may result because of the time required by the inspector to reach these less accessible stations after the failure of automatic equipment. Fortunately, automatic equipment failures are infrequent, but the seriousness of interruptions makes this consideration a vital one.

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(1) The word "operations" is here used in the sense of grouped activities and not steps of a process.—(Ed.)

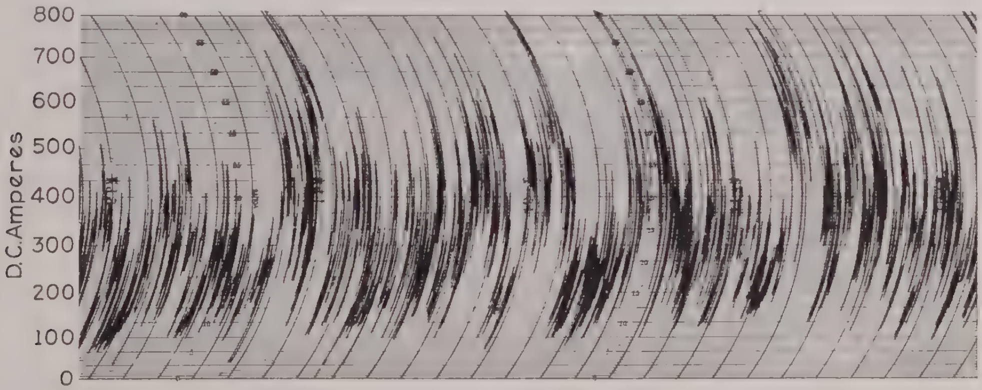


Fig. 1. Reproduction of a Recording-ammeter Curve of a Mining Load
From 10 a.m. to 2 p.m., right to left

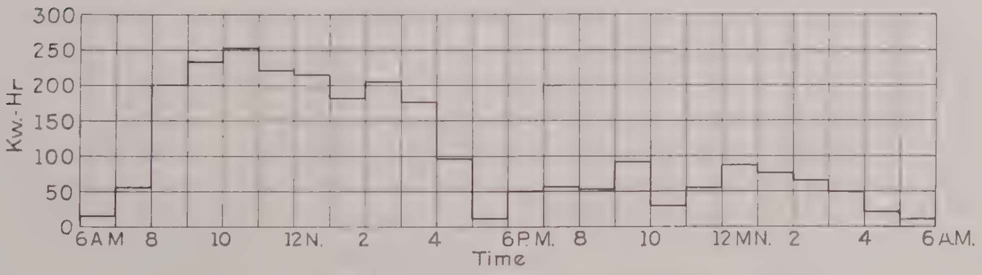


Fig. 2. Kilowatt-hour Consumption Curve Corresponding to the Current Curve Shown in Fig. 1

First Automatic Substation

The Company placed its first full automatic substation in operation in September, 1921. This station is located at Eckman, W. Va., and consists of two 275-volt, 300-kw. synchronous converters with transformers rated 13,200/206 volts. At that time both the Company and the customer questioned the operation of an automatic substation and its installation was largely experimental. For this reason, in addition to the full automatic equipment, manually-operated switching devices were furnished so that the machines could be operated independently of the automatic control. Since this station was put into operation it has been manually-operated but twice and then only for short periods while minor repairs were being made. The Company's experience with this station has indicated clearly that manual equipment in addition to automatic equipment is not warranted.

Distribution Survey

In the fall of 1922 a complete survey of all the Company's direct-current substations was made with the idea of increasing the efficiency and lowering the operating and maintenance costs. Alternating-current and direct-current watthour meters were installed on all machines, and in some cases recording direct-current ammeters were used to determine the load characteristics. Readings of kilowatt-hours were taken regularly and tabulated in a report form showing machine input, output, and efficiency, load-factor based on machine capacity and running hours, per cent direct-current transmission loss, power billed, and overall direct-current system efficiency. This investigation continued over a period of six months and resulted in the permanent "Monthly D-c. Substation Report" which accurately indicates operating conditions. Fig. 4 is an extract from one of these reports.

The original investigation indicated some of the converting machinery to be of such low efficiency that it could economically be replaced by more modern and efficient units; that some of the stations were overloaded or incorrectly located with respect to the load, or that where more than one station fed the same direct-current system the power was not being economically distributed. Direct-current feeder losses were likewise determined and the feeder conductor increased where a saving could be shown. Specific cases which necessitated changes in machines occurred in connection with the Cherokee Substation requiring a more efficient machine of the same capacity and Itman and Boissevain requiring larger machines in new locations.

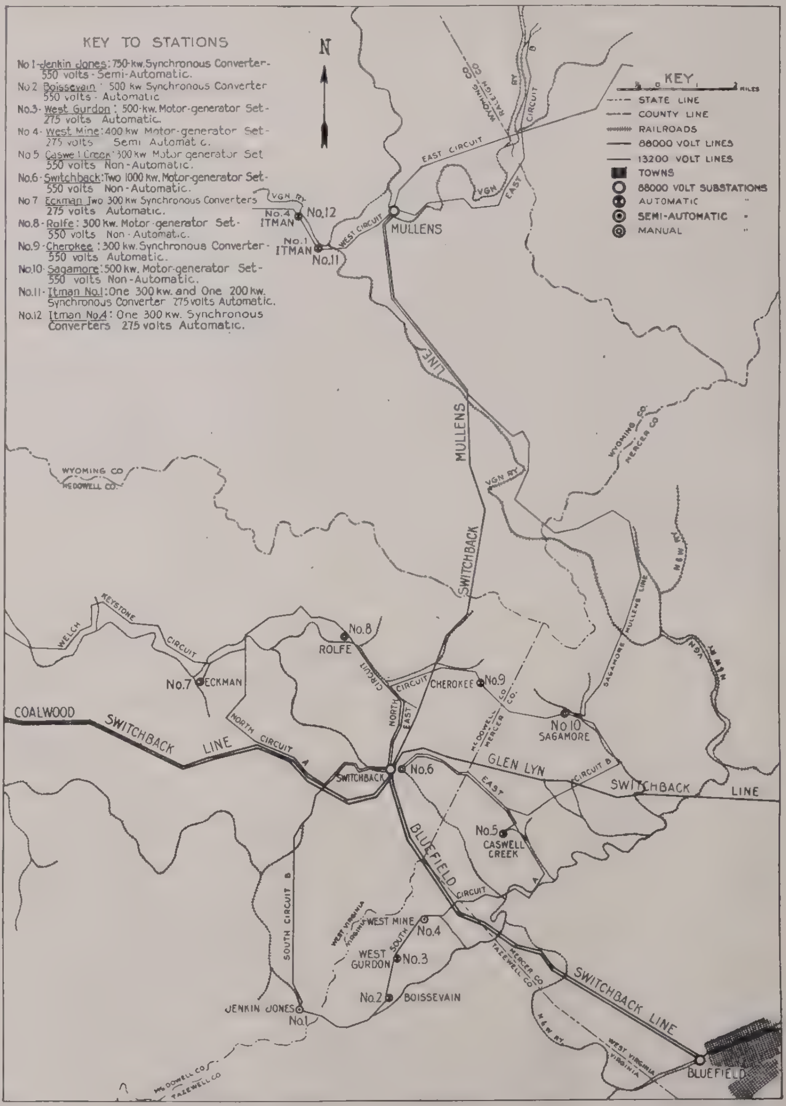
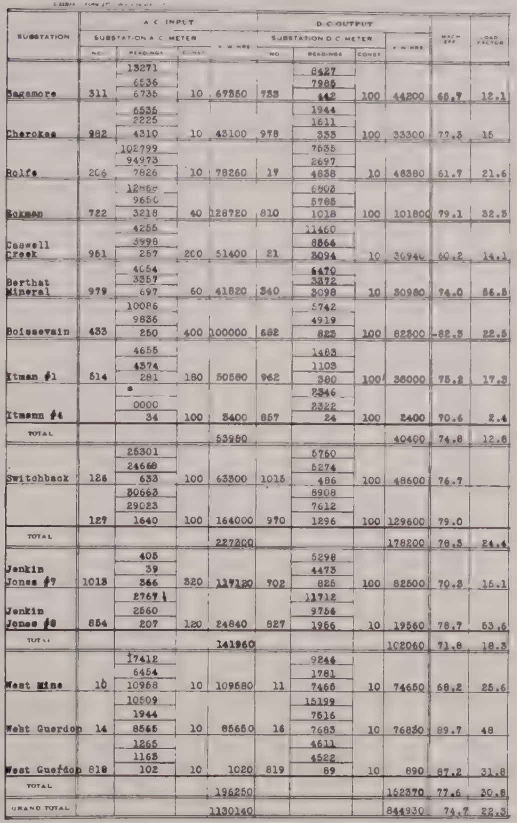

KEY TO STATIONS
No 1-Jenkin Jones: 750-kw. Synchronous Converter-550 volts - Semi-Automatic.
No 2 Boissevain: 500 kw Synchronous Converter 550 volts - Automatic
No.3- West Gurdon: 500-kw. Motor-generator Set-275 volts Automatic.
No 4- West Mine: 400 kw Motor-generator Set-275 volts Semi Automatic.
No 5 Caswell Creek: 300 kw Motor generator Set 550 volts Non-Automatic.
No.6- Switchback: Two 1000 kw. Motor-generator Set-550 volts Non-Automatic.
No 7 Eckman Two 300 kw Synchronous Converters 275 volts Automatic.
No.8- Rolfe: 300 kw. Motor-generator Set-550 volts Non-Automatic.
No.9- Cherokee: 300 kw. Synchronous Converter-550 volts Automatic.
No.10- Sagamore: 500 kw. Motor-generator Set-550 volts Non-Automatic.
No.11- Itman No.1: One 300 kw. and One 200 kw. Synchronous Converter 275 volts Automatic.
No.12 Itman No.4: One 300 kw. Synchronous Converters 275 volts Automatic.
N
KEY
MILES
STATE LINE
COUNTY LINE
RAILROADS
88000 VOLT LINES
13200 VOLT LINES
TOWNS
88000 VOLT SUBSTATIONS
AUTOMATIC "
SEMI-AUTOMATIC "
MANUAL "
EAST CIRCUIT
VGN RY
No.4 ITMAN
No.12
No.1 ITMAN
No.11
WEST CIRCUIT
MULLENS
MULLENS LINE
WYOMING CO
McDOWELL CO
WYOMING CO
MERCER CO
VGN RY
SWITCHBACK
N & W RY
KEYSTONE
WELCH
CIRCUIT
No.8
ROLFE
No.7 ECKMAN
COALWOOD
SWITCHBACK LINE
NORTH CIRCUIT A
NORTH EAST
CIRCUIT
CHEROKEE No.9
McDOWELL MERCER
No 10 SAGAMORE
SAGAMORE
MULLENS LINE
SWITCHBACK
No.6
GLEN LYN
EAST
CIRCUIT B
SWITCHBACK LINE
No.5 CASWELL CREEK
BLUEFIELD CIRCUIT
SOUTH CIRCUIT B
WEST VIRGINIA VIRGINIA
WEST MINE No.4
SOUTH
WEST GURDON No.3
No.2 BOISSEVAIN
JENKIN JONES No.1
MERCER CO TAZEWELL CO
SWITCHBACK LINE
N & W RY
WEST VIRGINIA VIRGINIA
BLUEFIELD
McDOWELL CO TAZEWELL CO

Fig. 3. District Served by the Appalachian Power Company and Locations of Its Converting Stations

Selection of Equipment

In choosing equipment for the stations, the confronting problem was to determine whether motor-generator sets, converters, manually-operated equipment, semi-automatic equipment, or full automatic equipment best suited the individual conditions. For reasons that will not be discussed in this article, synchronous converters were selected in all cases where new machines were required. Whether manual, semi-automatic equipment (manually controlled on the alternating-current side and equipped with a reclosing circuit breaker on the direct-current side) or full automatic equipment were chosen depended upon previous operating conditions. In some cases operators were required for other purposes such as sectionalizing 13,200-volt lines and operating auxiliary equipment for the customer. In these cases manual or semi-automatic equipments generally prove to be most economical. In cases where there are no duties other than the care of the substation and where the operator's living conditions are poor, full automatic equipment eliminating the use of operators entirely is generally most economical. Where one day and one night operator are normally used, the night operator may be eliminated by the use of semi-automatic equipment with a bell alarm to indicate at the operator's quarters when the alternating-current side is tripped out automatically.



SUBSTATION	A.C. INPUT				D.C. OUTPUT				MACH. EFF.	LOAD FACTOR
	SUBSTATION A.C. METER			K.W. HRS	SUBSTATION D.C. METER			K.W. HRS		
	NO.	READINGS	CONST.		NO.	READINGS	CONST.			
Sagamore	311	13271 6536 6736	10	67350	733	8427 7985 442	100	44200	65.7	12.1
Cherokee	982	6535 2225 4310	10	43100	978	1944 1611 333	100	33300	77.3	15
Rolfe	206	102799 94973 7826	10	78260	17	7535 2697 4838	10	48380	61.7	21.6
Bokman	722	12868 9650 3218	40	128720	810	6803 5785 1018	100	101800	79.1	32.5
Caswell Creek	961	4255 3998 257	200	51400	21	11460 8864 3094	10	30940	60.2	14.1
Berthat Mineral	979	4054 3357 697	60	41820	340	6470 3372 3098	10	30980	74.0	56.5
Boissevain	433	10086 9836 250	400	100000	682	5742 4919 823	100	82300	82.3	22.5
Itman #1	514	4655 4374 281	180	50580	962	1483 1103 380	100	38000	75.2	17.3
Itmann #4		* 0000 34	100	3400	857	2346 2322 24	100	2400	70.6	2.4
TOTAL				53980				40400	74.8	12.6
Switchback	126	25301 24668 633	100	63300	1015	5760 5274 486	100	48600	76.7	
	127	30663 29023 1640	100	164000	970	8908 7612 1296	100	129600	79.0	
TOTAL				227300				178200	78.5	24.4
Jenkin Jones #7	1018	405 39 366	320	117120	702	5298 4473 825	100	82500	70.3	15.1
Jenkin Jones #8	854	2767 2560 207	120	24840	827	11712 9756 1956	10	19560	78.7	53.6
TOTAL				141960				102060	71.8	18.3
West Mine	10	17412 6454 10958	10	109580	11	9246 1781 7465	10	74650	68.2	25.6
West Guerdon	14	10509 1944 8565	10	85650	16	15199 7516 7683	10	76830	89.7	48
West Guefdon	818	1265 1163 102	10	1020	819	4611 4522 89	10	890	87.2	31.8
TOTAL				196250				152370	77.6	30.6
GRAND TOTAL				1130140				844930	74.7	22.3

*Prorated.

Fig. 4. Extract from a Monthly Direct-current Substation Report of the Power Company

To determine the amount which can be economically spent for re-equipping a substation, the saving in operating cost is capitalized at 15 per cent. In other words, the cost of operating a manually operated station less the cost of inspecting an automatic station divided by 0.15 is the amount that the Company can invest for automatic equipment. The operating cost of a manually operated station includes operators' salaries, the cost of maintaining Company owned dwellings for operators' use, and miscellaneous operators' supplies. The 15 per cent at which the saving is capitalized represents the sum of 7 per cent interest, 6 per cent depreciation, and 2 per cent taxes and insurance. For these calculations the maintenance costs of automatic and non-automatic stations are considered the same.

Where the original converting equipment was not changed and where the operators lived close to the substation, it was found more economical to make such stations semi-automatic and to use one operator. The stations made semi-automatic are Jenkin Jones and West Mine. At West Guerdon and Caswell Creek full automatic equipment was installed with the present motor-generator sets. At Sagamore, Rolfe, and Switchback no changes were made since the operators at these stations have duties other than operating the substations.

Type and Construction of the Substations

In stations where automatic equipment was applied to original converting apparatus, the arrangement conforms as nearly as possible to the original layout. As far as possible, the automatic panels were located in the same place as the hand-operated panels, and the same cables and small wiring used. In one instance it was necessary to rearrange the equipment to make room for the automatic panels.

In the stations where all the equipment was replaced, a standard layout was used, the general arrangement of which is shown in Fig. 5. The station layout is for one unit, but additional units can be added.

In the layout of the stations one of the first questions was whether all the equipment should be indoors or part indoors and part outdoors. Layouts were made both ways and it was found to be more economical to put all the equipment indoors. A standard sheet-steel building 30 ft. by 20 ft. is used for all single-unit stations. The buildings are such that standard bays can be added. For a two-unit station a bay 20 ft. by 20 ft. is added to the standard building. The steel building is ventilated by grated openings near the floor level and by ventilators in the roof. In future construction it is proposed to run an air duct from the outside of the building under the floor to the opening beneath the machine, omitting the grated openings except at the side of the building near the transformers.

In the new stations, synchronous converters are used and the voltage is stepped down by transformers from a line voltage of 13,200 to the converter voltage. The incoming line enters the 30-ft. side of the building near the end on which the standard bay for the second unit may be added. Just inside are the disconnecting switches, lightning arresters, and control transformers. The line continues to the opposite side where it connects to the transformer bus. For a two-unit station the bus is extended in the opposite direction for the second transformer installation. With this arrangement no change is required in the original layout and the same drawings are used by simply inverting them. The apparatus is arranged so that it can be readily inspected and is easily accessible for maintenance. There are special I-beams installed over the machines for supporting blocks, to permit the machines to be quickly dismantled for repairs. All of the stations are equipped with 3-in. by 3½-in. single-stage air compressors operated by 1-h.p., 110-volt, single-phase motors. The air compressors are connected to air tanks 14 in. by 48 in., and from these tanks air is taken for cleaning the equipment. Lightning arresters are used on the outgoing direct-current lines as well as on the incoming alternating-current lines.

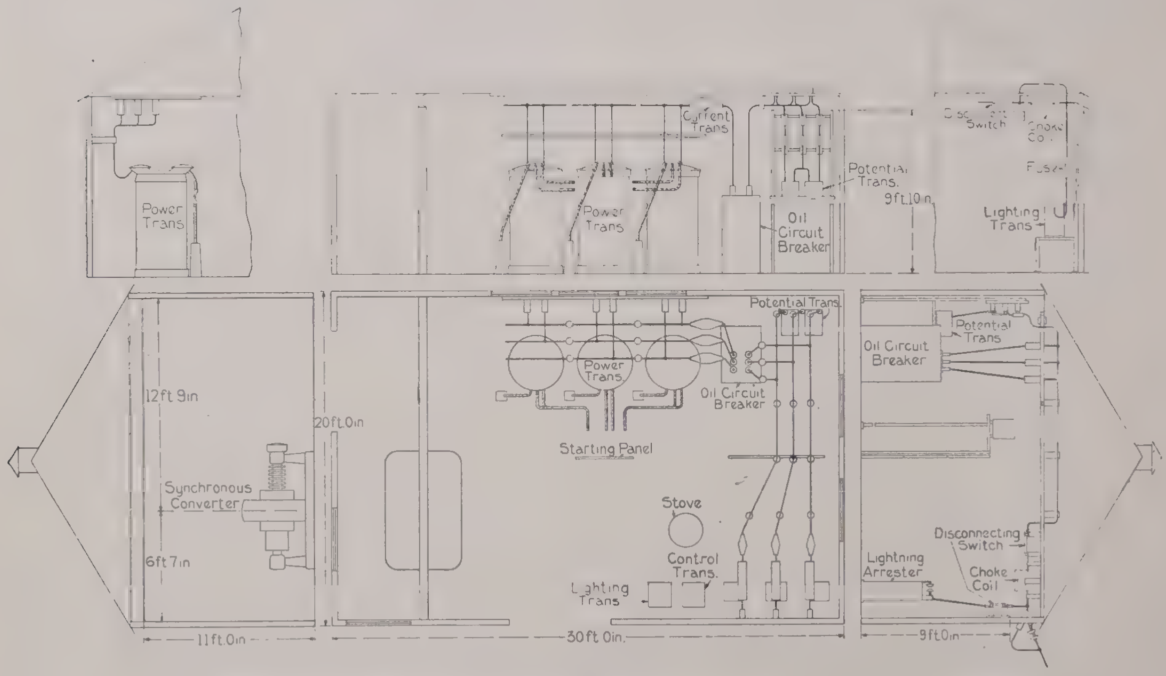


Fig. 5. Standard Layout Adopted for the Single-unit Automatic Substations, Capable of Later Expansion for Additional Units

All machines have both alternating-current and direct-current watthour meters; and in some of the stations where the peak loads are heavy, three-minute demand elements are installed on the watthour meters. In multiple-unit stations, or where more than one station feeds the same direct-current network, one or more of the machines can be shut down at night and on Sunday by means of time clocks. Four of the stations have these clocks installed. On week days the machines in these stations run from 7 a.m. to 5:30 p.m. They are shut down at 5:30 p.m. on Saturday and restart at 7 a.m. Monday morning. The West Guerdon machine is remotely controlled from West Mine by pilot wires. These stations are one and one-half miles apart and feed into the same direct-current system. Under normal conditions the West Guerdon machine is shut down at night by a time clock. If for any reason the West Mine machine fails or becomes overloaded, the operator at West Mine can start the West Guerdon machine at once by the pilot-wire system. Flashover relays which are manually reset are used on all 550-volt, direct-current machines. In event of a flashover, the stations are shut down and interrupt service until an inspection is made.

It has been the Company's experience that one flashover on a 550-volt machine will not damage it sufficiently to make a shut down necessary; therefore, arrangements are being made to install an auxiliary relay with the flashover relay for the purpose of allowing machines to flash over three times before the stations are locked out.

Recording voltmeters provided with eight-day clocks are installed on the secondary side of the power transformers to indicate the duration and time of interruptions. Occasionally customers report interruptions at such periods which the charts show the converting machinery to be in operation. These interruptions are obviously because of direct-current system troubles causing the reclosing contactor to remain open. Such interruptions are of course beyond the Company's control and the charts serve to indicate to the customer the true conditions.

Inspections

The importance of careful and thorough inspections of automatic substations cannot be overestimated. In order to obtain satisfactory and continuous service, all of the equipment must be maintained in perfect working order. In general it can be said that automatic equipments are complicated. There are a great many points where troubles may develop such as sticking contacts, the binding of mechanical parts, and circuit connections becoming loose or opened. It is logical to expect that any or all of these troubles may develop unless the equipment is regularly inspected and minor faults corrected as they occur. For these reasons the company has a regular inspector of automatic substations who reports directly to the Operating Engineering Department. It requires approximately four days to make the weekly inspections of the stations. The remainder of the inspector's time is spent keeping the records and taking care of special troubles.

It is the practice of the Company to give each station a regular inspection once each week. Very frequently at the time the inspector visits a substation the machines cannot be taken out of service, and consequently a thorough inspection cannot be made at such times so it is necessary to determine from the customer when he can conveniently be interrupted. Except in a few cases the machines can be taken out of service late in the day, but where this is not practicable the thorough inspection is made on Sunday.

One of the duties of the inspector is to familiarize the customer as far as possible with the operation of the automatic equipment and to make known to him the difference between an automatic and a non-automatic station so far as it affects the operation of his mine. The most striking example of the customer's misunderstanding of the equipment is the operation of the direct-current reclosing contactor. In a number of cases when the customer has reported a station shutdown, the inspector has found that the entire trouble resulted from a short-circuit within the mine and that the reclosing equipment functioned properly. In such cases the customer was told of the existing short-circuit and that it had to be cleared before the contactor would close automatically. On several occasions when direct-current contactors have been held open because of short-circuits, customers' employees have forced the contactors closed by hand thereby damaging the equipment. In order to prevent the automatic equipment from being accessible to unauthorized persons, all substation buildings are locked and only the customers' mining superintendent and electrician are provided with keys.

An inexperienced customer usually feels that the direct-current reclosing feature causes unnecessarily prolonged interruptions, but after having learned to use it as a device for locating short-circuits he finds it a decided convenience. To determine the location of short-circuits, the direct-current feeder sectionalizing switches are opened and closed consecutively. The switches which arc heavily as the contacts break indicate either a short-circuit or a load. These switches are left open for a short interval and if the short-circuit has been cleared from the source, the direct-current contactor recloses. The contactor not only facilitates the locating of trolley and feeder troubles, but minimizes interruptions and eliminates the excessive strains put on the converting equipment by closing in on short-circuits.

The inspector is provided with a special form which covers as nearly as possible the inspection of the equipment. The object of these forms, in addition to giving accurate records of inspections, is to call the inspectors' attention to common faults which might ordinarily be overlooked. Space is also provided for meter and operation counter readings; the time, duration, and cause of interruptions; a record of spare parts used; and detailed comments of troubles found, which are entered under the head of "Remarks." In order that the inspector may have a complete record of previous inspections a carbon copy of each station's report is kept at the station, the original being filed at the General Offices.

The inspection consists mainly of the examination of all contacts and the brightening of their surfaces by filing or sandpapering; the operating of the relays and contactors by hand to determine whether they operate freely; the inspection of operating coils, machine windings and bearings for excessive heating; the examination of exposed wiring for loose connections; the inspections and replacement of worn alternating-current and direct-current brushes, and noting as the equipment is put through its operating sequence whether all devices operate correctly. A competent man is employed as an inspector and is given full responsibility of maintaining the station in perfect operating condition. A clean and neatly arranged station is easiest to maintain and the inspector is required to keep the stations in first-class order at all times.

The annual cost of inspections per station is the inspector's salary and expenses divided by the number of stations. This figure is now approximately $400 per station, but will be reduced when other automatic stations are installed because the present number of stations does not require the total time of one inspector.

In order that the inspector may put faulty devices in first-class condition at the time of the inspection, the most frequently needed spare parts are kept in stock. To avoid unnecessary duplication, the parts are distributed among the various stations as much as possible. Some of the more infrequently used parts are kept at the Company's General Stores. Steel lockers are provided in which these parts and other supplies such as tools, fuses, lamps, sandpaper, clean rags, and lubricants are kept. Since a complete set of spare parts are not kept at each substation, special care must be taken to have accurate records at all times of where certain parts are located and the devices for which these parts are interchangeable. Considerable changes in automatic equipment devices have been made since the installation of the Company's first station and the stations are of varied types and voltages. For these reasons the investment in spare parts is higher than if the majority of parts were interchangeable. The Company's investment in automatic equipment spare parts is approximately $150 per station.

Maintenance

By maintenance is meant all material used and the work done on a station to keep it in good operating condition. Minor maintenance work, such as changing coils, changing and dressing contacts, replacing brushes, and cleaning stations, is done by the inspector. The major part of the maintenance work is done by the Maintenance Department which includes such work as rewinding armatures, replacing field coils, grinding and undercutting commutators, changing contacts on oil circuit breakers, filtering oil in transformers and all other work necessary to keep the station in first-class condition. The Maintenance Department is notified by the inspector when such work is necessary.

One of the special duties of the Maintenance Department is the cleaning of all machines once each month by the use of compressed air. Machines that are located near tipples or in extremely dusty places are cleaned every two weeks. Since it has been the practice of the Company to clean all machines regularly, the number of failures of fields and armatures have been reduced approximately 50 per cent.

Previous to the installation of automatic equipment, it was the opinion of the Company that the maintenance of automatic stations would be higher than that of non-automatic stations, because an operator could make minor repairs and locate troubles before they become serious. The Company's experience in this respect has been just the opposite, the reason being that a thorough inspection of the stations is made once a week by an inspector who is a more competent man than the ordinary operator.

Conclusion

Automatic substations when properly applied are adaptable to mining loads, and in a great many ways have shown their superiority over manually-operated stations. When new converting stations are proposed, it is assured they will be automatically controlled if the installation is practical.

Standardization in automatic equipment is desirable. It simplifies operation and maintenance and reduces the number of spare parts kept in stock.

For successful operation of automatic equipment it is necessary to have regular inspections made by a competent inspector.

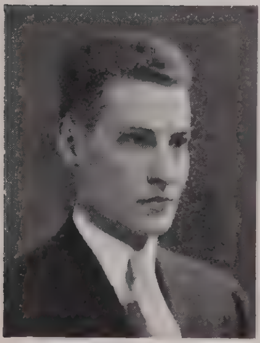
The service rendered by automatic substations has been satisfactory both from the customer's and the Company's point of view. Better service has been given at a lower cost.

Automatic Substations in the Mining Industry

Influence of Automatic Substations in Reducing Costs and Increasing Production—Preference for Single-unit Stations—Motor-generator and Synchronous-converter Stations—Successful Parallel Operation—Location of Substations with Respect to Load—Resulting Economies

By E. L. Hough

Automatic Station Division, Switchboard Department, General Electric Company



E. L. Hough

THE present status of the bituminous coal industry is comparable to the situation of the electric railways of a few years ago. Although the spot price of coal is approximately 60 per cent higher than it was before the war, the increases in cost of mining operations have been so enormous that at the present time it is only the most efficiently managed mines that are able to show a profit.

The electric railway but a few years ago found itself confronted by a similar situation because of the competition of the automobile and the rising costs of operation with an insufficient increase in fares. This situation was partially met by a reduction of operating expenses brought about by the employment of labor-saving devices, such as the one-man car and the automatic substation. To the latter must go much of the credit for the financial improvement in electric railways; and it would appear that the mining industry could profitably consider a similar solution of its present problem.

Relation of Automatic Substations to Mining Costs

The operating conditions of mine haulage systems are not far different from those of electric railway systems; the distances are not so great but the voltage is usually lower. The automatic substation usually offers advantages that are not sufficiently realized by mine managements who desire to obtain the most reliable source of power at a minimum cost. It is a significant fact that one of the largest bituminous mining companies in Pennsylvania is installing automatic substations as a part of its rehabilitation program. This company has permanently closed many of its poorer mines and is taking advantage of every improvement in mining equipment to provide for cheap mining of coal from its better mines. As a result of this company's study, it was decided to make large investments in automatic switching equipment both to modernize its present substations and to equip new stations which are to be located at strategic load centers.

The first automatic stations to be installed in mines were placed in operation in 1921 and the number of installations per year has increased rapidly since that time. It is interesting to compare the selling price of bituminous coal for the same period. In 1920 the spot price f.o.b. mine for bituminous coal rose to $8.75 per ton. In 1921 the industrial depression carried the price down to $2.30, and except for a brief period in 1922 when the price rose to $5.45 per ton the price has fallen lower until it is now about $2.00 per ton. The high prices of the post-war period caused an enormous expansion of the industry; new mines were opened everywhere and at the present time it is only the most efficient mines that are able to operate at a profit, however slight.

One of the major reasons for the increasing interest in automatic substations is the growing appreciation of the ability of such a station to reduce the cost of mining. The cost of electric power has remained almost stationary since before the war, except that the capital charges on investment and the substation attendance charges have risen materially.

A study of the electrical data on a large number of mines, having outputs up to more than a million tons per year, has revealed the fact that the electrical costs vary from 3 cents per ton for partially electrified mines up to 35 cents per ton for an inefficient operation that is producing a very small amount of coal. The average cost of electrical power is in the neighborhood of 8.5 to 12.5 cents per ton plus the substation attendance and capital charges. It has been found that attendance charges often run from 10 to 25 per cent of the power cost. Hence, it seems that a fair average power cost, including attendance, would be 11 cents per ton. It can readily be seen that with coal at $8.75 a ton, the cost of electrical power would represent only approximately 1.2 per cent of the selling price of coal; but with coal at $2.00 a ton this figure becomes 5.5 per cent of the selling price. A saving of only 15 or 20 per cent of 1.2 per cent did not look promising or urgent enough to warrant the investigation of possible cost reducing equipments; but a possible decrease of 15 or 20 per cent of a 5.5 per cent item is sufficient to warrant a consideration of means to that end. This in part explains the increased interest that coal operators are showing in automatic and partial-automatic switching equipment.

Another definite reason for increasing interest is the realization of freedom from labor trouble, both direct and indirect, that comes from automatic operation of substations. No doubt, a similar study in the metal mining industry would reveal similar conditions.

Relation of Automatic Substations to Increased Production

Of perhaps greater importance than the reduction in direct power cost is the increased productivity of the mine brought about by the use of automatic equipment. In the early days substations were located near the load centers and an operator was provided for each station, such a layout being desirable because labor was cheap and the location at the load center minimized the amount of feeder copper necessary. Increasing labor costs have made necessary the location of substations where pump, machine shop or other attendants could, in addition to their other duties, look after the substation. This has resulted in a marked lowering of the standard of service since the attendant is overburdened with other duties, or does not appreciate the loss of production, or the dissatisfaction of the miners occasioned by an unnecessary lengthening of the time that power is off the line.

Because of the difficulty of obtaining skilled operators at the present time, the mine owner sometimes finds himself called upon to pay unusually large bills for repairs to substation apparatus which has been damaged by careless or inexperienced operators. Miners who are dissatisfied because their work is hindered by a faulty power supply oftentimes leave their work and the mine produces less as a consequence. The location of substations where operators are available, rather than at load centers, is not good practice because it necessitates a large amount of feeder copper or results in poor trolley voltage. Low voltage is responsible for a lowering of the speed of motors on locomotives, pumps, and cutting machines, thereby contributing to armature burnouts and other motor troubles that probably would not occur if the motors were run at their rated voltage. Low trolley voltage also results in excessive distribution losses.

When contemplating the purchase of automatic switching equipment, it is usually possible to evaluate the saving that will be made by eliminating the operator, but many of its other advantages are not so evident. For instance, it has been found that the cost of substation maintenance is reduced, that interruptions of the power system are fewer and of shorter duration, that distribution losses are often reduced and trolley voltage improved by the installation of automatic substations near load centers.

Automatic Substation Equipment

The design of the earlier automatic substations which were installed in mining service paralleled, very closely, the design of similar stations for railway service. It was appreciated, however, that the more or less temporary character of a mine installation made necessary an equipment that would be simpler than the railway type and one that could be tested and maintained by men who were not as familiar with control equipment as were the railway electricians. The basic scheme of control has not been materially changed since the original installations were made, but many improvements have been incorporated in the devices and various control schemes and apparatus have been developed for meeting difficult operating problems that have appeared as automatic switching equipment has been applied under widely varying sets of conditions.

Most of the earlier substations were equipped with "load-limiting" feeder equipment, often in combination with some sort of a "load-indicating" equipment. The load-limiting equipment was found to be unsuitable for most mine installations because it lowered the trolley voltage during overload periods and thereby tended to aggravate rather than improve conditions. At the present time all fully automatic substations are being supplied with automatic reclosing feeder equipment which is designed to remain closed on ordinary overloads that are within the overload capacity of the machine, to trip on current values in excess of machine capacity and to reclose when the short-circuit or excessive overload has been removed from the feeder or trolley. It has also become general practice to equip manual substations with the same type of feeder equipment.

During the four years from 1921 to 1924 inclusive, a large number of installations have been made under widely varying conditions. Equipments rated at 100 to 300 kw., supplied from a 2300-volt alternating-current line and furnishing 275 volts direct current, are usually considered standard for mining service although installations having supply voltages up to 13,200, direct-current voltages up to 600, and capacities as high as 750 kw. have been made.

Single-unit vs. Two-unit Substations

About one-third of the machines are installed in two-unit stations, thus giving a ratio of approximately five single-unit stations to one double-unit. The trend seems to be away from the double-unit automatic station; the statistics covering installations indicate a substantial and steady decrease in the percentage of machines installed in two-unit stations. This decrease is probably due to a better appreciation of the proper field of the automatic substation. In general, the saving in attendance charges alone does not justify the installation of automatic control in a multiple-unit mining substation although its use may be warranted by the better operating conditions obtained under automatic control. The use of single-unit automatically controlled stations located as near the load centers as possible seems to be the most desirable layout. The stations are tied together through the trolley and sometimes through feeder cable also. In such cases it is desirable to sectionalize the mine trolley and feeder system automatically in order to localize the short-circuit or overload. In this way, power can be maintained on most of the mine system and there is no unnecessary loss of time or mine production while someone in the mine hunts up the trouble.

Control of Operation

There are several possible methods of giving the impulse to start a mining automatic substation and the scheme to be used depends upon the particular conditions to be met. If the automatic station is fed by an independent alternating-current feeder, it may be started by energizing this feeder and stopped by cutting the power off this circuit. The most common method is to have someone give the starting impulse by closing a small switch which may be located within the station or at a convenient point some distance from it. If the cycle of operations at a mine is definitely established, a time switch may be used advantageously for controlling the starting and stopping of the station.

In the railway and lighting fields considerable attention is being focused on the use of supervisory control equipment, whereby the automatic stations may be controlled by a load dispatcher, but this system does not seem to be adapted to the conditions in the mining industry. (The writer is familiar with but one such installation in the mining field.) Where considerable savings may accrue by eliminating the running-light losses, it is possible to use a load-responsive starting and stopping scheme. However, this scheme necessitates a certain time delay and this is usually not desirable in a mine-power supply. Consequently, the latter scheme is seldom used although there may be a few locations where its use might be desirable. In two-unit substations it is common to start the second machine when the first becomes overloaded. This may be accomplished by a contact-making ammeter and a time-delay device, or by a thermal relay which will cause the second machine to start when the first one tends to become overheated. Of these alternatives, the first is probably the better for mining service. As soon as the starting impulse is given, the automatic switching equipment performs all of the operations necessary to start and protect the machine properly and to connect it to its load.

The following descriptions apply to standard equipments but only minor modifications are necessary to adapt the control to fit conditions other than standard. It is usually advantageous to apply standard equipment whenever possible in order to take advantage of quantity production, and often the manufacturer can ship the complete substation equipment from stock.

Automatic Motor-generator Substations

Since the control for a motor-generator set is the simplest it will be briefly described first. The starting impulse serves to energize an alternating-current voltage relay if the machine has not been shut down by one of the protective devices. If three-phase alternating-current voltage sufficient to start the set is available, a master-control contactor is closed to energize an oil-immersed starting contactor. When this contactor closes it connects the starting compensator to the line and the synchronous motor, and the set starts. As the motor is coming up to speed its field is short-circuited through a field-discharge resistor and a current transformer to which a synchronous-speed indicating relay is connected. As the motor comes up to speed, the current induced in the field winding holds the synchronous-speed relay contacts open, but when approximately synchronous speed is reached the induced current dies down and the relay closes its contacts to close the field contactor which applies field to pull the motor into step. After the motor falls into step, the field builds up and a relay in series with the motor field, when energized, opens the starting and closes the running contactor to disconnect the compensator from line and motor and to connect the motor directly to the line. During the entire sequence of operation the machine is adequately protected against abnormal conditions; such as improper supply voltage, incomplete start, overheated bearings, overheated machine windings, field failure, alternating-current overload, direct-current overload, etc.

If the generator is to be connected to a system which may be supplied by several machines, a voltage-directional relay measures the direction and amount of voltage difference between the machine and its load. If the machine voltage is higher than that of the line, the automatic reclosing equipment is allowed to connect the machine to its load as determined by load conditions. This reclosing equipment is arranged to prevent reclosure on too great a value of load under either stub-end or multiple-feed conditions, to trip on overload, and to interpose a short-time delay between the opening and closing of the feeder circuit.

The station is shut down by opening the circuit of the master control contactor. When this contactor is de-energized, it opens and the various control devices assume the "off" position in readiness for restarting. A complete 300-kw. automatic motor-generator substation is shown in Fig. 1.

Synchronous-converter Substations

The starting impulse in a synchronous-converter substation energizes an alternating-current voltage relay as in the motor-generator station to close the master control contactor if proper three-phase supply voltage is available. This contactor completes a circuit to close the starting contactor and to start a small field-flashing motor-generator set. The starting contactor connects the converter to the partial voltage taps of the transformer. The converter starts and when synchronous speed is reached a synchronous-speed indicating relay, which is connected across the converter commutator, is energized and causes the field-flashing contactor to close. This contactor connects the field, which has been broken up during starting, to the small field-flashing set to establish correct polarity. When the converter polarity is correctly established as determined by the field-changing relay, the field-flashing contactor opens and the field contactor closes to make the converter self-excited. As soon as the field builds up, the starting contactor is opened and the running contactor is closed to connect the converter to full voltage. The running contactor in closing completes

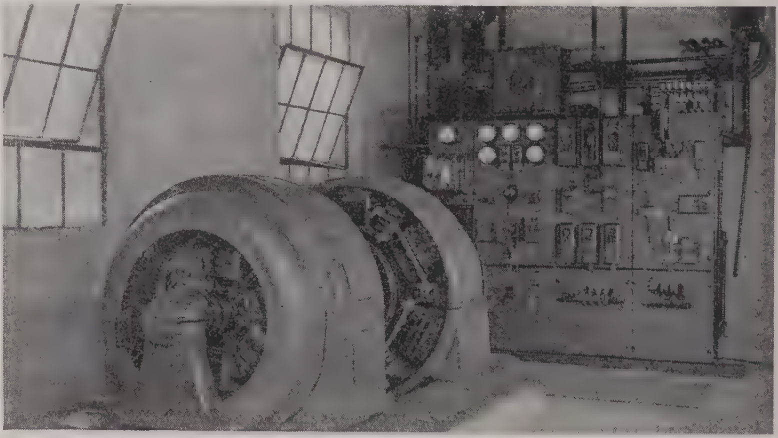


Fig. 1. Automatic Substation of the Heisley Coal Company at Nanty Glo, Pa., Showing 300-kw. Synchronous Motor-generator Set Controlled by Automatic Equipment. On the Right-hand Panel is Mounted the Equipment for a 1500-amp. Stub-multiple D-c. Reclosing Feeder

a circuit to operate the motor-driven brush-operating mechanism and the brushes are lowered onto the commutator. As soon as this operation has been completed, the converter is connected to its load in a manner similar to that employed in the motor-generator equipment just described. The protective features provided are similar with the addition of protection against incorrect brush position. A fully automatic 300-kw. synchronous-converter substation having one outgoing feeder is shown in Fig. 2.

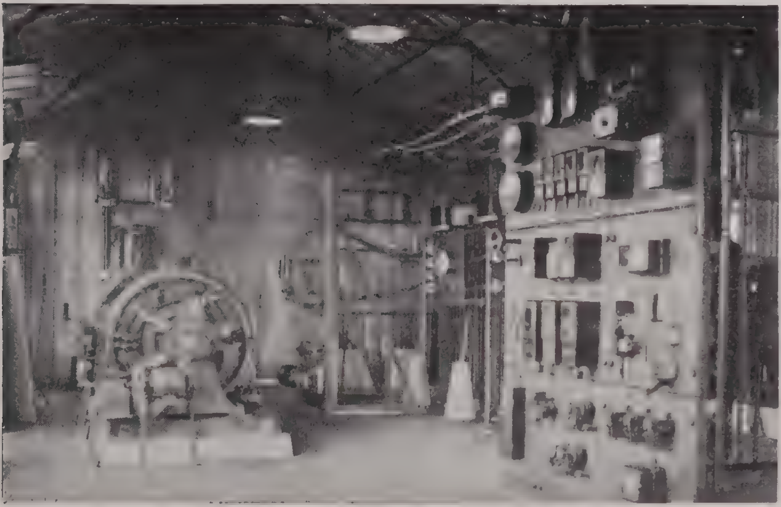


Fig. 2. The Appalachian Power Company's Itman Substation No. 4, Containing a 300-kw. Synchronous Converter and its Automatic Control Equipment

When the circuit of the master-control contactor is opened, the machine shuts down and all devices return to the "off" position. Unless the shutdown has been caused by power failure, the brushes will be raised from the commutator. It is to be noted that the machine is always started with the brushes raised since it has been found that this is necessary in order to eliminate the severe sparking which causes burning of the brushes and commutator if the brushes remained down. The practice of raising the brushes has been standard in manually controlled substations which are equipped with interpole converters, and it has not been deemed advisable to depart from this practice in an automatic station in order to lower the first cost of the equipment.

Parallel Operation

Where several units are to be installed in the same station, it is usually desirable to design the equipment to exactly suit the conditions to be encountered in the installation under consideration. There are many cases, however, where it is desirable to have two units in a single station for a time and later split this into two single-unit stations. To fill this need a multiple-unit design was developed and numerous installations have been made. One of these multiple-unit motor-generator equipments is shown in Fig. 3. Any number of feeders with any number of units may be used in a station of this type. The feeders are arranged so that when a machine becomes overloaded sufficient feeders will be tripped off to reduce the load on the machines to a safe value without dropping the entire station load. Each individual feeder is arranged to trip upon the occurrence of a short-circuit or overload and to reclose automatically a brief interval after the overload has been removed. They will function on either stub-end or multiple feed and cannot reclose on a short-circuit under any circumstances.

Considerable difficulty has been encountered even in manual practice because over-compounded machines do not always operate well in parallel. When the machine is cold the voltage of a direct-current generator may build up 10 or 12 per cent higher than when the machine is hot. When the machines are located in single-unit stations with a considerable amount of feeder and load between units, this excess voltage does not give rise to any unusual operating difficulties. When both units are in the same station, however, this becomes a more serious matter since the cold machine will usually take all of the load and reverse the hot machine off the line. This difficulty may be lessened to some extent by under-compounding the machines, though not a desirable expedient as a rule. In some cases, that is where the resistance of the feeder between stations is very low, this under-compounding is necessary in order to obtain proper balancing of loads between substations.

A load-regulating relay has been developed for multiple-unit stations which has been found to be very satisfactory in service. As a general rule, the relay is called upon to operate for 20 or 30 minutes until the cold machine warms up. After this the machines, which are equalized as in manual practice, divide the load satisfactorily. If they have not been designed to divide the load proportionately at all loads, the regulating relay may operate continuously to balance the load properly. The equalizing contactor, which is now a part of mining equipments, has been specially designed for this service. In order to reduce its resistance it is built without the customary blowout coil and is equipped with silverplated contacts.

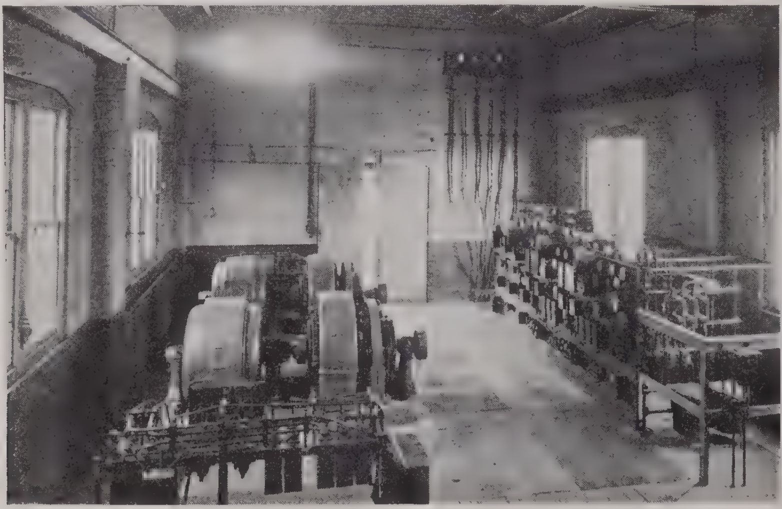


Fig. 3. Synchronous Motor-generator Sets, Automatic Control Equipment and Stub-multiple D-c. Reclosing Feeders in the Automatic Substation of the Jeddo Highland Coal Co., Jeddo, Pa.

Ordinarily the parallel operation of synchronous converters does not present any difficulty. This is due to the fact that there is but a small difference between the direct-current voltage of hot and cold machines and their characteristic curves are slightly drooping rather than rising.

Power-factor Correction

The problem of good power-factor maintenance seems to be assuming increasing importance day by day and there is little doubt but that the power-factor clause of the power contract will play a larger part in mine-power costs in the future. Automatic motor-generator substations may be equipped with a power-factor regulator to improve the system power-factor. In fact, several such installations have been made. Synchronous converters are designed to be operated at unity power-factor and are not suitable for power-factor correction. It is customary to set the field on these machines to give unity power-factor at about 75 per cent load. Many operators make a practice of controlling the direct-current voltage by means of the field rheostat. This practice is wrong and should be discouraged. Changing the excitation of the converter by adjusting the field rheostat affects the power-factor of the machine and seriously increases the heating of the converter. The small change in voltage is due to the regulating effect of leading current flowing through a reactance, i.e., the transformers.

Location of Substations

There is usually a question as to whether a substation should be located on the surface or underground. It is usually desirable to locate the machines as near to the load as possible, but where the station may be installed not more than a few hundred feet from its load it is probably desirable to locate it on the surface or at some entry which is extended to the outside. The surface substation is ordinarily cheaper to construct, more easily ventilated, not subject to the dampness and corrosion that would be encountered underground, and it is usually cheaper to install a single-conductor low-voltage cable than a three-phase high-voltage one. However, numerous installations of automatic stations have been made underground and have given good satisfaction. Equipments so installed are specially treated to withstand moisture. A salt-mine installation which has been in service for two years has given no trouble. In fact, it is probably better off underground where the air is relatively dry than it would be at the shaft head when it would be subjected to salt dust and moisture as well.

Partial-automatic Applications

Many mine operators, who do not feel that a fully automatic substation is justified under their conditions, install partial-automatic stations. Such a station is one which is started by an operator and left to run by itself. If trouble occurs the machine is shut down and someone must visit the station to restart it. It can be seen, therefore, that such an automatic station should not only have an automatic reclosing feeder equipment on the direct-current end but should also be equipped to protect against reverse power, bearing overheating, and such other hazards as the particular installation warrants. There seems to be a more or less unfortunate condition existing in the application of partial-automatic stations in that installations lacking sufficient protective equipment are made. Manufacturers are in a position to provide suitable protection for almost any possible operating contingency, and unless suitable protective relays are installed it is safer to consider these so-called partial-automatic stations as manual ones and operate them as such.

Economies Resulting from Automatic Substations

When making a study of a mine distribution system to determine the feasibility of automatic stations for the case in hand, it will be found that the largest determinable saving will accrue from the elimination of the operator or operators. It has been found that this attendance charge is as high as $3000 or $4000 per station if three shifts are employed. It is customary to allow for the expense of inspecting the automatic substation but this charge is not always fair to the automatic equipment since the combined inspection and repair charges for an automatic station may not be more than the previous repair charges on the manual substation. One operator has reported a saving of $160 a month with practically no charge for inspection and repair. His original investment for the automatic equipment was in the neighborhood of $4000 (installed) for a 150-kw. machine. A yearly saving of $1920 will pay the entire cost of the automatic in about two years. And the electrician in charge reports that they have eliminated their biggest trouble; i.e., keeping the night operator awake. The electrical apparatus for an automatic motor-generator station costs approximately 40 per cent more than that for a manual station, but it is doubtful if the installation and building cost will be more for the automatic than for the manual since a smaller and simpler building may be used. A similar equipment for a synchronous converter runs about 65 or 70 per cent higher than the corresponding manual equipment. A partial-automatic station costs from 5 to 20 per cent more than the corresponding manual station, depending upon the protective features provided.

There has always seemed to be a doubt in the mine operator's mind as to the ability of his electrical crew to care for an automatic station properly. When automatic stations were first applied to the mining industry, they seemed to be very complicated and instructions for their care and operation were more or less meagre. Within the past few years much has been accomplished in simplifying the control and in materially improving the instructions for maintenance, so that the average mine electrician of today does not experience any difficulty in making them work.

The automatic substation has proved its worth in the mining industry and its widespread adoption is a certainty as soon as mine operators become aware of its advantages.

Automatic devices are never guilty of inattentiveness

Automatic Substations of the Oregon Electric Railway

Experience in Automatic Operation of a 1200-volt, D-c. Railway under Steam Railroad Rules and Regulations—Territory Served—Substation Equipment—Reasons for Automatic Operation—Savings Secured

By E. R. Cunningham, *Electrical Superintendent, Oregon Electric Railway*
and Geo. N. Barker, *Portland Office, General Electric Company*

E. R. Cunningham

ABOUT eighteen years ago an enterprising engineering firm in Boston, in co-operation with some local financiers, conceived the idea of an up-to-date electric railway system for the Oregon country. This idea was developed; and on January 1, 1908, the Oregon Electric Railway started operating in the Willamette and Tualatin Valleys.

Territory Served

The line as originally built ran from Portland southward, up the valley of the Willamette a distance of 52 miles to Salem, the capitol, and west from Portland up the Tualatin Valley 28 miles to Forest Grove.

The Willamette Valley was already served to a certain extent by the main line of the Southern Pacific from Portland in the north to San Francisco in the south, and the smaller but equally fertile Tualatin Valley by branch lines of the same road. The Oregon Electric, however, provided more frequent and satisfactory passenger service for the towns in these two very mild and fertile valleys; and the freight business in a comparatively short time attained very desirable proportions. It became obviously a valuable feeder for a long-haul system, and it was undoubtedly for this reason that the line was acquired jointly by the Great Northern and Northern Pacific in 1910. This not only provided a valuable feeder for the two transcontinental railroads, but opened up the northern and eastern markets to the producers in the Willamette and Tualatin Valleys by the use of the Spokane, Portland and Seattle Railway, also owned jointly by the Great Northern and Northern Pacific, and operating on a water grade between Portland and Spokane, Wash., where it joined the Great Northern and Northern Pacific.

G. N. Barker

Immediately after its acquisition by the two Northern lines, the Oregon Electric was placed under the management of the Spokane, Portland and Seattle. In 1911, the electric line was extended from Salem south for a distance of 70 miles to Eugene, at the upper end of the now famous Willamette Valley, so that the line now traverses the entire length of both the Tualatin and Willamette Valleys. The present total route mileage is 154, with 180 miles of track.

General Features of Operation

The Oregon Electric began life as a 600-volt line, but following the general trend toward high direct-current voltages, it was changed over to 1200 volts in 1912 and began operating at this higher voltage in August of that year. There is still 25 miles of line inside the city operating on 600 volts, and therefore all equipments are arranged for 600/1200-volt operation.

A rather interesting feature in the development of the road is that for a period of two or three years after it started operating it was conducted in accordance with the generally established practice of electric lines; but since it has been under the management of the Spokane, Portland and Seattle Railway, it has been operated in accordance with standard steam road practice and under steam road rules and regulations. The trains are heavy and move at comparatively infrequent intervals, which is contrary to the usual practice on electric lines, particularly in the last two or three years. This condition was the determining factor in the adoption of automatic substations; in fact, the heavy trains and infrequent service made the use of this type of equipment almost imperative.

Automatic Substations

After a thorough analysis of the service conditions, the management decided to equip its substations with full automatic control and reclosing feeders. An order was accordingly placed in January, 1922, for the equipment for seven stations. There are eight substations on the system, but the one at Multnomah, nearest to Portland, is a ticket and baggage station, and as attendance is therefore necessary, this station was not changed to automatic.

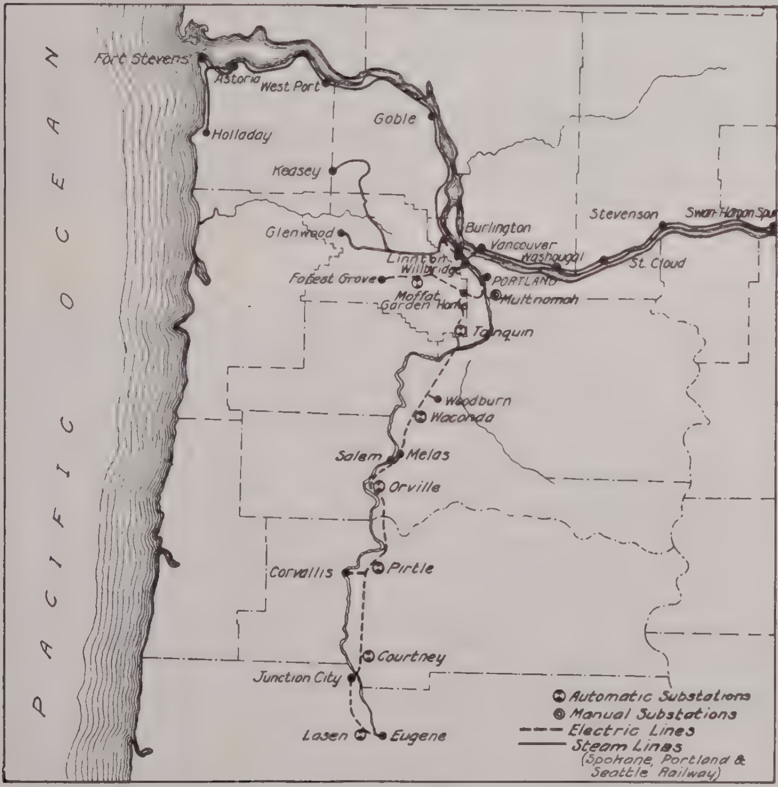


Fig. 1. Map Showing the Territory Served by the Oregon Electric Railway and its Connections, Together with the Railway's Automatic and Manual Substations

There are two 2-unit stations, Moffat and Tonquin, and five single-unit stations, Waconda, Orville, Pirtle, Courtney, and Lasen.

The two 2-unit stations each contain two 500-kw., 650-volt, 6-phase, synchronous converters connected in series, and the single-unit stations each contain one 500-kw., 1300-volt, 3-phase, synchronous converter.

The alternating-current power is supplied by the Portland Electric Power Co. for all stations from a 60,000-volt, 3-phase, 33-cycle circuit.

The substations are located approximately 20 miles apart. Seven of them are on the Portland-Eugene division and one on the Portland-Forest Grove division.

The first station to be equipped with automatic control was placed in operation on December 1, 1922, and the latest on September 1, 1923. Automatic operation has proved an entire success.

Operating Experience

During the time that the stations were manually operated, much trouble was experienced with flash overs caused by rapid and extreme fluctuations due to starting the very heavy trains. This was especially true when trains were near a station. The trouble was also due in part to the main breaker opening on the heavy overload, and the attendant being unable to reclose it until the train or trains had moved a considerable distance away on reduced voltage from more remote stations. This operating difficulty has been almost entirely eliminated with the automatic stations by the load-limiting resistors on the reclosing feeder equipments.

It is impossible to say too much in favor of these automatic substations. So far as trouble is concerned, one would not know that there were any substations on the system. All substation buildings are kept locked, entirely without supervision except for occasional inspections. All trains are running without delay. The operating and maintenance cost has been reduced from $43,837.54 per year to $10,604.70, or a saving of $33,232.84 per year for operating and maintenance alone. Further details are given in Table I.

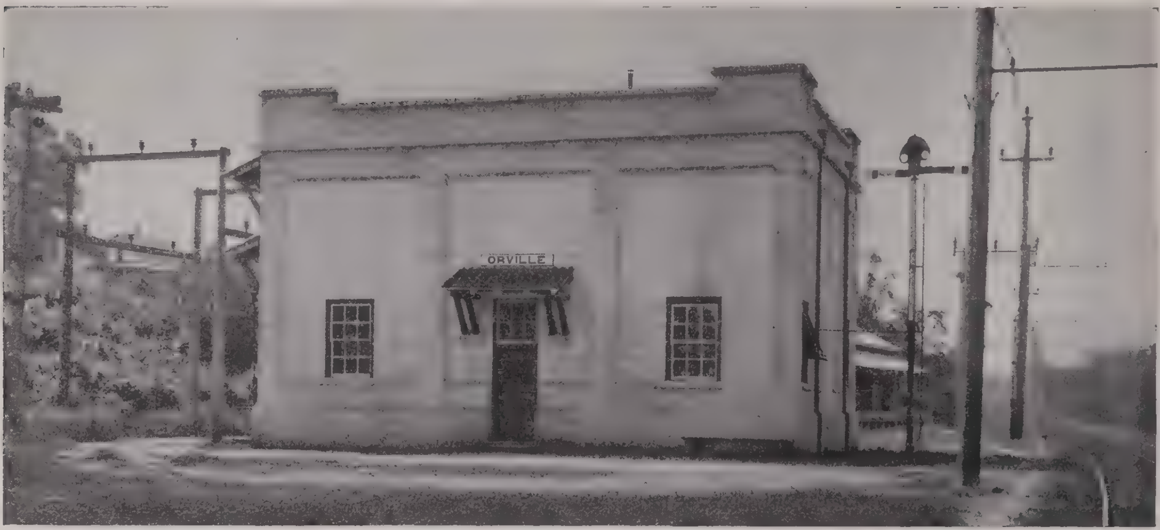


Fig. 2. The Orville Automatic Substation, Containing One 500-kw., 1200-volt Synchronous Converter

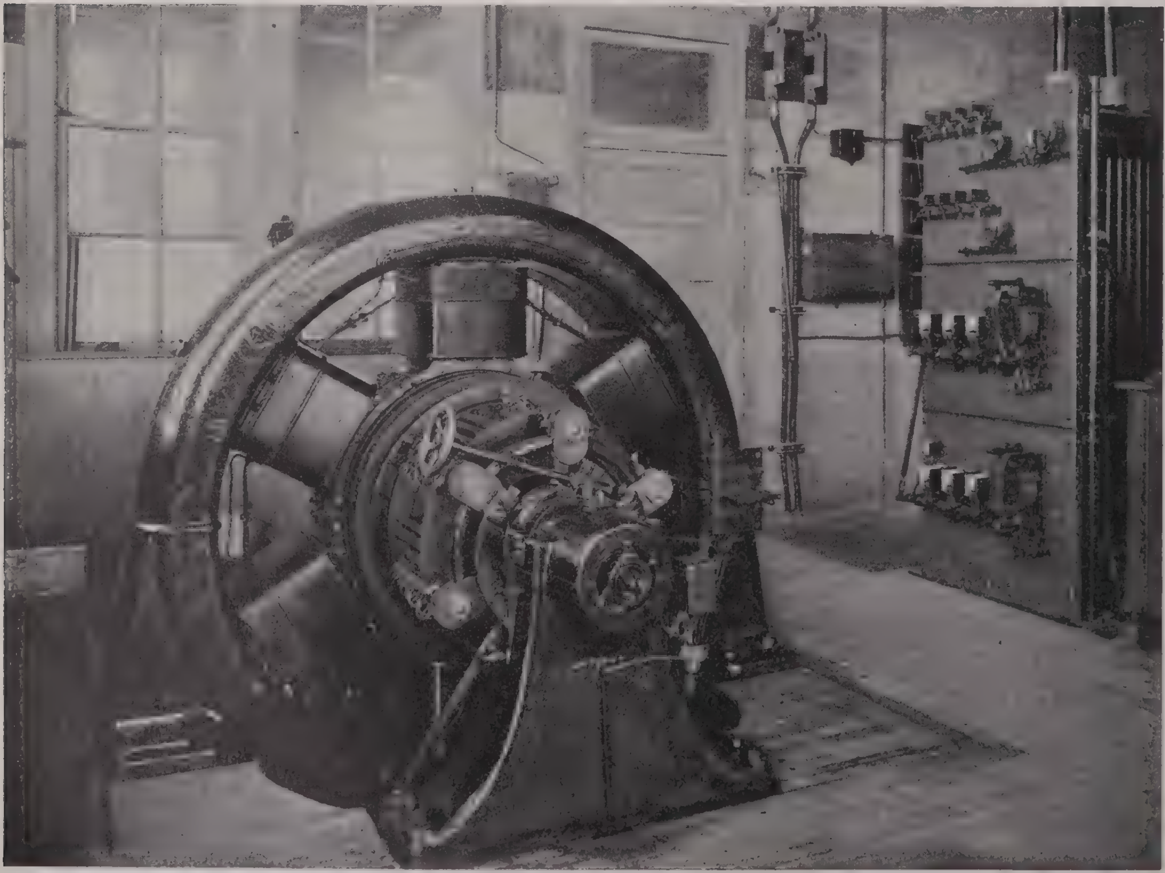


Fig. 3. Interior View of the Tonquin Automatic Substation, Showing a Starting Panel and One of Two 500-kw., 600-volt Converters that in Series Deliver 1200 Volts

Savings Through Automatic Operation

There has been a further saving of about $3000 per year on power because of more efficient operation under automatic control, due to the fact that the stations operate only when actually needed. This makes a total saving on operation and maintenance of $36,232 per year, or $5176 per station. The figures from which these savings were compiled were for the year 1921, the year just preceding the change to automatic operation, and for the year 1924 immediately following the change-over.

A still further saving could be made by making Multnomah automatic. The only reason this has not been done is that the Portland Electric Power Co., the central station furnishing the alternating-current power, will probably be able to furnish 1300 volts direct current at an early date and thus do away with this station which is near the corporate limits of the city of Portland. It costs more to operate and maintain this one manually-operated substation than it does to maintain and operate all of the seven automatic substations.

TABLE I

SUMMARY OF OPERATING AND MAINTENANCE EXPENSE

	1921	1924
Employees	$36,521.99	$3,264.59
Supplies and expenses	1,213.54	582.93
Equipment	6,102.01	6,757.18
	$43,837.54	$10,604.70
	10,604.70	
Savings by automatic operation	$33,232.84	

While the greatest saving has been in reduced operating cost due to the elimination of attendants, the cost of supplies and incidental expenses has been reduced more than 50 per cent.

Maintenance

The cost of maintenance and repairs was reduced about 50 per cent, which was offset by an increase in inspection costs. The requisite amount of inspection is of course more or less indefinite or indeterminate and depends on the personal judgment of the superintendent in charge, which in this case is one of the writers.

It is an excellent plan to pay substation maintainers on the same basis as the Chinese pay their doctors—for keeping them well. As long as they are well, payments are made, but cease when they are sick. The maintainers were formerly paid for repairing manually-operated substations after the trouble occurred. They are now paid for preventing trouble in the automatic substations. They also take care of telephone and telegraph systems, crossing signals, station lighting, and give first aid in trolley and transmission line trouble.

These men are stationed approximately 40 miles apart in houses formerly occupied by substation operators. Three of them are stationed outside of Portland and one in Portland. The latter gives a small portion of his time to the one station nearest Portland on the Forest Grove Division.

Before the substations were made automatic, there was but one maintainer located outside of Portland and from two to three in Portland. Under the present plan, quicker repairs can be made to telephone and telegraph breaks, crossing signal interruptions, station lighting, etc., so that operation has been made better in every respect.

Great improvement was immediately noticed in the operating conditions of the synchronous converters after the automatic control was installed. There was a very noticeable reduction in the temperature of the machines, especially on the commutators, and the chattering and squealing or singing of the brushes was entirely eliminated.

Both equipment and station remain clean for a longer period of time. There is a better and more consistent division of load between the stations, and operation in every respect has been greatly improved. While the operation was formerly uncertain and erratic and subject to the whim or caprice of the particular operator on duty, it is now economical and precise and in accordance with the actual service demands.

In brief, automatic operation has proved an unqualified success.

Automatic Substations on the Chicago, North Shore & Milwaukee Railroad

Extensive Provision of Additional Converting Equipment to Handle Large Increase in Traffic—Original Practice Automatic Substations Between Manual—Dependable Performance Justifies Re-equipping Manual Stations and Making New Stations Automatic—Data on Seven Years' Automatic Operation—Frequent Inspection Reduces Maintenance and Increases Reliability

By Charles H. Jones

Consulting Electrical Engineer, Chicago, North Shore & Milwaukee Railroad

During the past eight years the Chicago, North Shore and Milwaukee Railroad has enjoyed a remarkable growth as the outcome of an earnest effort to give a high quality of service to the communities that it serves. The result has been to increase its gross revenues from $1,157,191 in 1915 to $6,198,987 in 1924.

An inspection of Table I will indicate the increase in service which had to be provided to handle the increase in business. This in turn required large increases in power facilities.

In 1915 there was 9500 kw. in synchronous converters distributed along the line in eight manual substations; and by July of this year (1925) there will be 18,700 kw. of such converters in 17 stations, ten of these being automatic stations and seven manual stations, including one portable.

The first additions to the original system were made in 1917 with single-unit automatic substations spaced about half way between the existing stations. This practice has been followed since, as experience has demonstrated the soundness of the power-distribution principle that dictates the placing of connecting apparatus along the line in single-unit stations rather than concentrating several units in one station, especially on this type of railroad.

The first step of expansion by interspacing stations between the original stations has been completed, and now a start is being made on the second round of interspacing stations which is going to make the average spacing approximately three and one-half miles. At the same time, a program of adding additional feeder copper has been carried along so that now there is approximately 1,300,000 cir. mils of copper in the distribution and contact system between substations.

Due to the gradual manner in which the stations were added, a splendid opportunity was offered to determine the reliability of

TABLE I

CAR-MILES OPERATED

Year	Passenger	Express and Freight	Passengers Carried
1915	2,450,988	272,088	6,762,518
1916	2,830,317	348,320	7,459,689
1917	4,034,352	413,762	10,374,243
1918	5,355,632	517,744	11,875,249
1919	6,128,254	457,264	12,425,634
1920	7,074,419	587,940	13,388,238
1921	7,101,558	619,283	13,711,181
1922	7,872,871	964,826	13,426,371
1923	8,803,908	1,357,733	15,179,572
1924	8,996,429	1,468,514	16,047,678

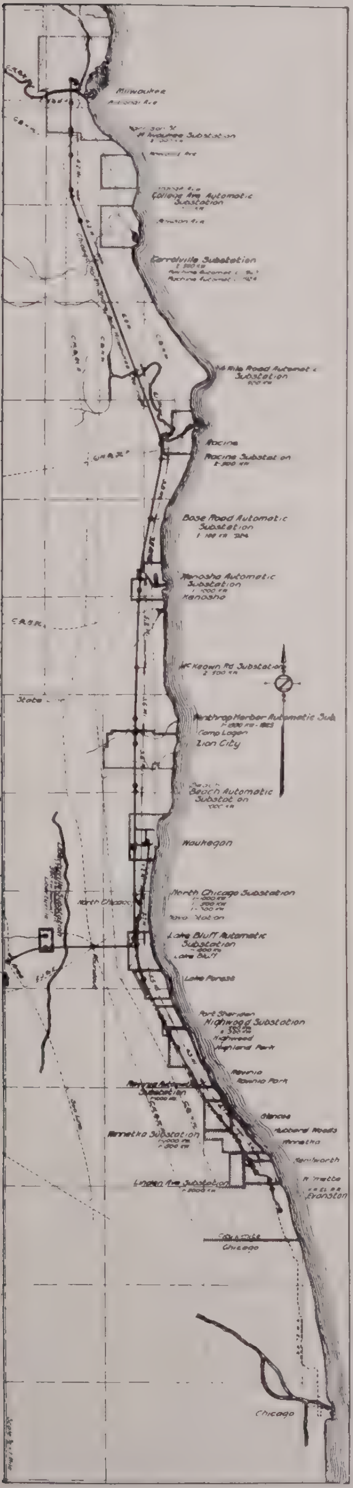


Fig. 1. Map of the North Shore Lines

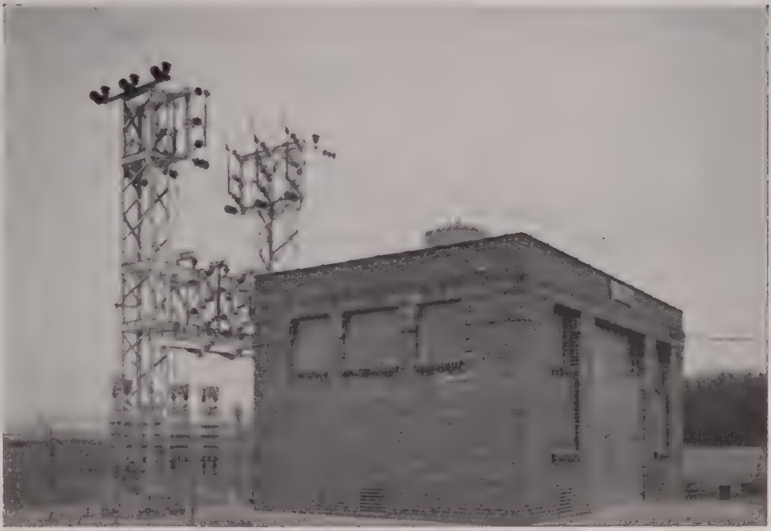


Fig. 2. Exterior View College Avenue Automatic Substation of the Chicago, North Shore & Milwaukee Railroad, Showing High-tension Structure and Lightning Arresters

the automatic substation as compared with the manual station and this service test has demonstrated beyond any question of doubt that the automatic equipments can be absolutely depended upon to render service equal to if not better than manual equipment. We now have no hesitancy about placing several automatic stations adjacent to each other and give practically no consideration to manual stations when installing additional stations. A program of adding automatic control equipment to some of the original

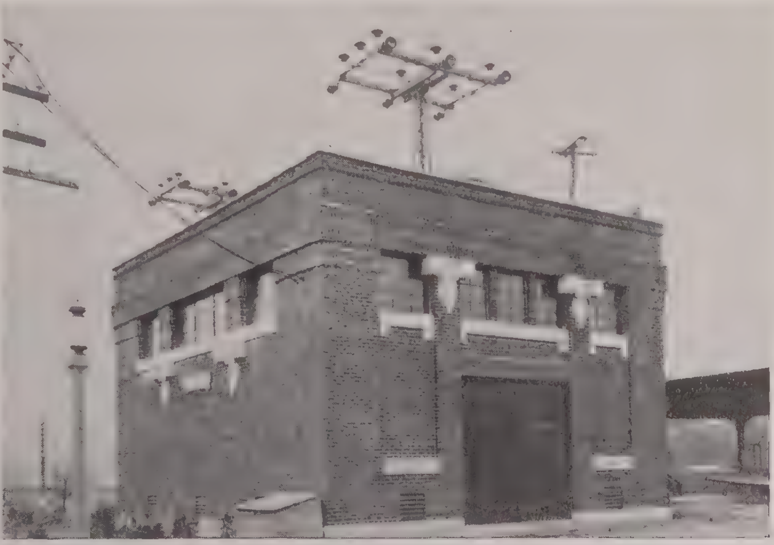


Fig. 3. Lake Bluff Automatic Railway Substation, Which Contains an Automatically Controlled 1000-kw. Synchronous Converter Unit

manual stations and removing the operator has been started; and in the course of time, operators will probably be eliminated in all but one or two of the original manual stations.

Table II shows plainly the severe test that automatic control equipment has been given on this system during the past seven years.

In the early years of automatic operation there were a number of control equipment failures, which averaged about one failure per 1000 operations, but as improvements have been made in the equipment these failures have been reduced until today they are almost negligible.

TABLE II

Station	Date Started	Capacity	Hours Operated	Number of Operations	D-c. Kw-hr. Output
* Beach	Dec. 5, 1917	1000	42,162	38,578	13,307,075
† Kenosha	Apr. 15, 1918	1000	31,947	76,955	8,599,580
Four Mile	Nov. 2, 1918	500	31,700	69,782	7,253,560
Lake Bluff	Feb. 26, 1919	1000	37,497	19,743	13,520,874
Libertyville	Dec. 6, 1919	300	31,705	35,686	3,096,179
Ravinia	May 1, 1921	1000	25,982	21,706	11,020,150
College	Oct. 27, 1922	500	9,062	28,680	2,274,450
Carrollville	Dec. 2, 1923	500	6,684	13,654	1,409,930
Bose Road		1000	Under construction		
Winthrop Harbor		1200	Under construction		

* The Beach substation started with a 500-kw. machine, which was changed to a 1000-kw. machine in May, 1922.
† The Kenosha substation started with a 500-kw. machine, which was changed to a 1000-kw. machine in March, 1925.

A regular inspection program has been followed out on all of these stations daily; and after seven years of experience we feel fully justified in continuing the practice, even where supervisory control has been superimposed on automatic control, as it affords an opportunity to forestall possible causes of trouble and insures the maximum reliability of service.

At the time the original installations were made, much discussion took place as to the amount of maintenance the automatic control equipment would require and it was our opinion that this would total a considerable item during the course of a year. This however has not proved to be the case, as there has been only a very small amount of automatic control equipment either repaired or replaced, even in the stations where we have had over 75,000 operations.

Since our first stations were installed almost eight years ago there have been many improvements in the devices making up the control equipment, which has gone a long way toward simplification and elimination of the number of devices required, but the fact that the original apparatus is today functioning equally as well as the modern equipment testifies to the ability and the foresight of the pioneers in the development of the automatic station.

At the time we were studying the application of automatic substations, careful consideration was given to building design and layout and although we have since kept abreast of the times we have found but little in the way of improvement to be made along these lines. Practically the only major change which has been made was in placing all of the high-tension equipment outside the building and reducing the building in size. In one of our original stations where we have since replaced the equipment with one of larger size, we have placed all the high-tension equipment outside, thus releasing enough room inside the building to accommodate a second machine if it ever becomes necessary.

Automatic Substations on the Chicago, Aurora & Elgin Railroad

One of the Early Railroads to Adopt Automatic Substations—Loads Amounting to 225 Per Cent Capacity—99.18 Per Cent of Several Thousand Starts Are Perfect—Attention Cut to 1/14 of Manual Station

By SAMUEL E. JOHNSON

Superintendent of Power Distribution, Chicago, Aurora & Elgin Railroad

The first automatic substation on the Chicago, Aurora and Elgin Railroad was installed at Warrenville, Illinois, during the year 1918. The work consisted of adding automatic equipment to the then present manually controlled 500-kw. synchronous converter; and the favorable results obtained from the operation of this automatic substation were a deciding factor in determining the type of equipment to install later. Two more automatic substations were installed on this property and placed in service in June, 1923. One of these was located at Bellwood, Illinois, and the other at Wheaton, Illinois. The Bellwood Substation is located on a double-track high-speed section in the territory where service is exceptionally heavy and frequent. The Wheaton Substation is located at the junction of the Elgin and the Aurora branches, with double-track main line to Chicago. These stations are identical in construction except that the Wheaton Substation is provided with three direct-current feeders, whereas the Bellwood Substation has only two.

These substations have a capacity of 1000 kw. each. The synchronous converter, switchboard, and load-limiting equipment are located inside the building, and the high-tension equipment, including the power transformers, is located outside the building. Fig. 1 shows the outdoor incoming line equipment, the location and arrangement of the lightning arresters, oil circuit breakers, current transformers, and power transformers; and Fig. 2 shows the interior of one of these substations.

The Bellwood Substation is located near a steam railroad crossing where exceptionally heavy load peaks occur, due to the slowing down and stopping of the trains at the interlocking plant controlling train movements over the crossing. The Wheaton Substation is located in the yards, near the car shops at Wheaton. This station is subjected to exceptionally heavy loads due to its proximity to the yards, where considerable freight switching is done, and to the heavy demands caused by the making up of trains for passenger service. This load, in addition to the regular train service operated on both the Aurora and Elgin branches and the double-track main line on this system, makes momentary demands upon this station of 225 per cent of the capacity of the converter.

The feeder equipments of these two stations include high-speed circuit breakers. Exceptionally good results have been obtained from this type of breaker and too much cannot be said for its reliability and dependability, as well as accuracy of performance. It is only natural that around the railroad yards many more short-circuits will occur than along the right-of-way, and the performance of the high-speed circuit breaker under these conditions at this point has demonstrated its great superiority over the old type circuit breaker in protecting the machines and direct-current distribution system.

After the first month of operating these two automatic stations, which is the time normally required to get the equipment properly tuned and regulated, very little trouble has been experienced. Since they were installed they have started up and shut down over 5857 times. Of the total number of times the converters have been started, there were but 48 failures of the stations to come in on the line when required, so that the percentage of perfect operation amounts to 99.18.

Of the total of 48 failures, 28 were caused by the improper timing of one of the time-delay relays, 4 were caused from blown high-tension fuses on the control transformer, 2 were caused by motor burnouts on the high-tension oil circuit breaker, and 14 were due to the operation of protective devices protecting against flashovers, short circuits, brush troubles, etc.

The astonishing feature of these automatically controlled converters, with proper load-limiting equipment, is their ability to move heavy trains whose demand is far in excess of the capacity of the substation. The load-limiting equipment operates as a cushion against the first heavy peak and after a very short period the load-limiting resistance is cut out, enabling the converter to apply its full capacity to the service.

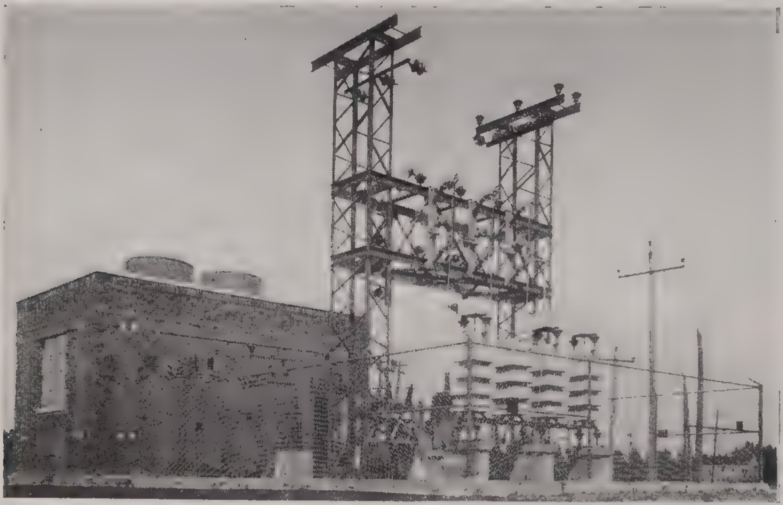


Fig. 1. Bellwood Automatic Substation. High-tension equipment, including lightning arresters, oil circuit breakers, current and power transformers, located outdoor

Our service is such that at times two six-car trains will start away from the station at the same time, each train normally demanding approximately 4000 amp., and by the automatic manipulation of the load-limiting feature in connection with the converters these trains are accelerated properly and moved along on schedule.

The converter at the Bellwood Substation is on the line approximately 18 hours a day, while the Wheaton Substation is on the line more than 23 hours a day.

The stations are visited each day by a man who makes a record of the station operation as taken from the Veeder counters on the different switches controlling the converter. He also changes the voltmeter charts which record the hours of operation and the duration of each time the converter is off the line. The regular inspection, which consists of a complete checking and inspection of all the equipment, is conducted weekly by two men. At this time the machine is shut down by the hand manipulation of some protective relay, the station cleaned, the contacts on all relays inspected, the setting of the various overload relays checked, the timing of time relays carefully noted, and general inspection and cleaning given to all equipment.

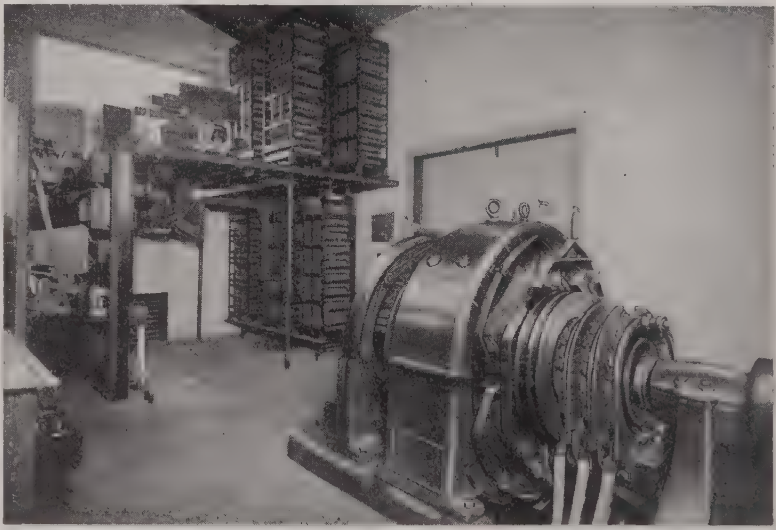


Fig. 2. Interior of Bellwood Automatic Substation, Showing 1000-kw. Converter, Part of the Automatic Control, the High-speed Circuit Breaker, and the Load-limiting Resistors

The operating man-hours per week for each of these stations is 12 as compared with 168 man-hours per week in our manually controlled stations.

Automatic Substations in Railway Service

Saving in Operating Costs a Prime Factor—Figures Given—Adaptability to Meet Severe Requirements—Reliable Performance Afforded by Complete Protection—Outstanding Features of Control—Types of Feeders—Two Substation Installations

By Clark E. Baker
Railway Engineering Department, General Electric Company

C. E. Baker

SINCE the installation of the first completely automatic railway substation, on the lines of the Elgin and Belvedere Electric Company in 1914, the General Electric Company has built over 280 automatic control equipments for use on 85 railway systems in 10 countries. It is therefore evident that the automatic railway substation has passed the development stage and is most assuredly a successful and important factor in railway systems.

Advantages of Automatic Substations

Automatic or non-attendant operation of railway substations was first conceived as a result of efforts to reduce the cost of operating railway systems. Automatic starting, stopping, and protection afforded a means of eliminating substation attendants except when needed for routine inspection and maintenance. By means of the load-demand feature, the substation was permitted to operate only when actually required, thus reducing the running-light losses and consequently power consumption at the substation.

The saving realized by the elimination of continuous attendance is unquestionably the greatest economic advantage of the automatic substation. As an example, compare a typical installation of automatic and manual substations of 600-volt 500-kw. capacity. The complete cost of such an installation is approximately as shown in Table I.

The application of automatic control to existing manual substations likewise proves an attractive investment.(1)

The saving in power effected through the operation of a substation only when load can be economically delivered to the system often is of importance and especially so in the case of interurban substations where service is infrequent. This is quite evident when it is considered that the amount of power required to bring a converter from rest to synchronous speed is approximately equivalent to the power consumed by the same converter running light for a period of two minutes. It does not necessarily follow, however, that a substation can be economically shut down during any cessation of power demands in excess of two minutes because too frequent operation naturally increases maintenance, but it may be taken as an indication of the extent to which power saving is possible.

TABLE I

	Manual	Automatic	
Complete electrical equipment	$11,000	$18,000	
Installation and building	8,100	8,500	
	$19,100	$26,500	
Additional first cost for automatic substation			$7,400
Interest, depreciation, taxes, and maintenance	$ 2,870	$3,980	
Cost of operation	4,000	600	
	$6,870	$4,580	
Yearly saving			$2,290
Per cent saving based on additional cost of automatic equipment			31

Experience has revealed that the automatic substation presents other advantages difficult to capitalize but frequently of sufficient weight to govern the selection of automatic in preference to manual control. Of these less tangible advantages, the elimination of the uncertain human element is perhaps the most important. The control is arranged to start and stop the substation as though by an operator but at the direction of a master element which may be a voltage relay, time switch, or some form of remote control. The various operations are performed in a fixed sequence in a definite time and with unvarying accuracy. Should an emergency arise the control functions without hesitation, delay, or error to protect the equipment and machines.

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(1) An example of this character is given in the article, "Automatic Substations of the Oregon Electric Railway," by E. R. Cunningham and G. N. Barker, page 421.—(Ed.)

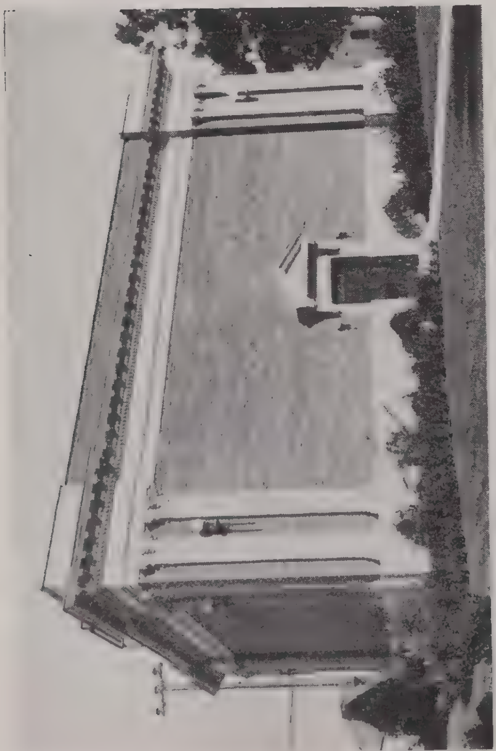

Fig. 1. Exterior View, West Adams Noiseless Substation, Los Angeles Railway Corp., Los Angeles, Calif. This station contains a 1000-kw. automatically controlled synchronous converter and equipment

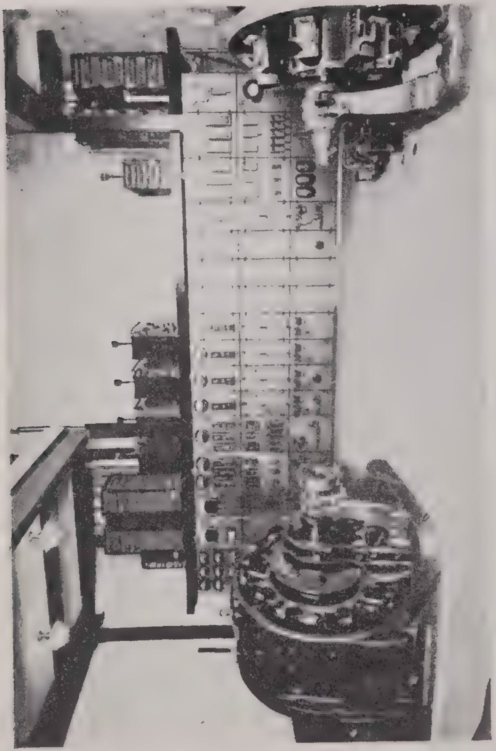

Fig. 2. Interior, Melrose Substation, Los Angeles Railway Corp., Showing Two Automatically Controlled Synchronous Converters

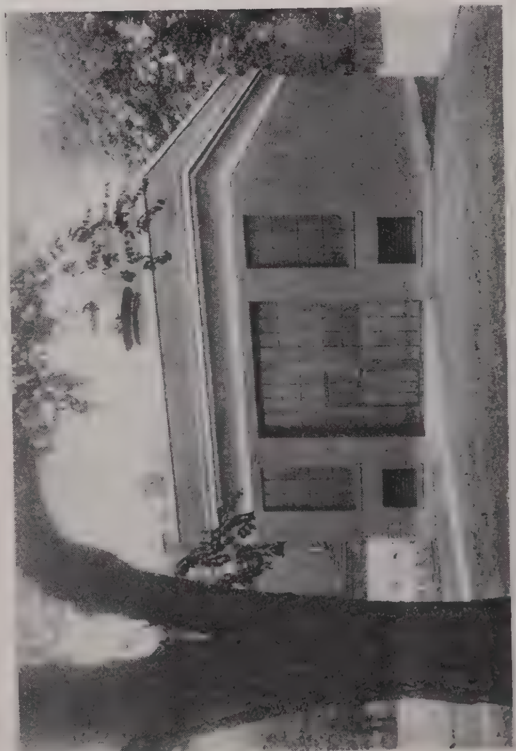

Fig. 3. Maple Avenue Automatic Substation of the United Railways Co., of St. Louis, Containing a 1000-kw. Synchronous Converter and A-c. Reclosing Feeders

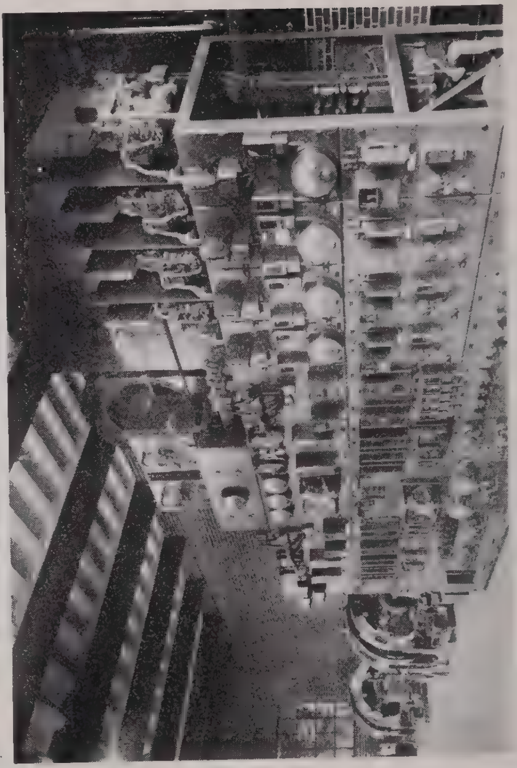

Fig. 4. Evans Avenue Automatic Substation of the United Railways Co., St. Louis, Another Example of Synchronous Converter and Reclosing Feeders

Complete and Positive Protection

An automatic substation must be protected against every condition that may arise. Excepting special cases, the conditions usually guarded against comprise at least the following:

Direct-current overload
Alternating-current overload
Reverse current
Low alternating-current voltage
Incorrect polarity
Overspeed
Damage due to flashover or grounds in machine
Excessive machine temperatures
Excessive bearing temperatures
Excessive heating of load-limiting resistance
Wrong position of brushes
Loss of field
Single- or reverse-phase starting
Single- or unbalanced-phase running
Incomplete start

The usual manual substation is protected against only a relatively few of these—such as overloads, overspeed, and sometimes reverse current—and in none of them is the protection as complete or as effective as in the automatic substation. Protection against other abnormal conditions depends upon the experience and careful observation of the attendant. Obviously the vastly superior protection in an automatic substation is an invaluable asset.

Capability of Service

The ease with which congested traffic can be handled, and the rapidity with which service can be resumed after a shutdown, have been demonstrated repeatedly. Through the use of load-limiting resistance or some form of automatic voltage control, the automatic substation can be quickly returned to service and it remains connected to the system delivering power at a reduced voltage as long as practicable.

It is quite evident from several successful special applications that automatic substations may be employed to accomplish results otherwise uneconomical or impracticable, of which the noiseless substation is an outstanding example.

Many street railway companies have been confronted with objections to the noise created by their manual substations and in some instances to such a degree that extension or service improvement programs have been interrupted by a refusal of residents to permit the installation of such substations. For cases of this sort, special soundproof entirely-enclosed substation buildings have been constructed. The difficulty of securing attendants for a substation thus completely isolated from the outdoors is obvious. Automatic substations have therefore greatly simplified this problem.

Two Installations

The New York Central Railroad found it advisable to improve the voltage during rush hours between two substations of the Grand Central Terminal electrification. An investigation revealed that a manual substation of considerable capacity would be required; but, by using an automatic substation and taking advantage of its automatic voltage control features, it would be possible to supply the load demand by installing a 2000-kw. motor-generator set at a point between the two existing substations. The substation was designed with practically a constant-current output characteristic resulting in approximately a 100-volt increase in potential between the substations during rush hours. This first installation was so satisfactory that a duplicate unit was recently added to the substation and another similar substation is now in process of installation at another location on the system. A 1500-kw. synchronous motor-generator substation of this type is also now being built for the Key System Transit Co., Oakland, Calif., for installation on the pier fill in San Francisco Bay, approximately 10,000 ft. from the Oakland shore in San Francisco Bay.

The Public Service Electric & Gas Company of Newark, N. J., recently completed an automatic station known as the Miller Street Substation which includes two 1500-kw. synchronous motor-generator sets supplying power to a double railway bus. The local heavy feeders operate from a 550-volt bus and the longer outlying feeders from a 600-volt bus. When one motor-generator set is sufficient to supply the total load both buses are connected together through a tie breaker and operated at 550 volts. When the load is too great for one unit, the second machine is started and supplies the 600-volt bus which is disconnected from the 550-volt bus by the opening of the tie breaker. Provision is made for reversing the operation of the sets to equalize service. Here again automatic control performs operations which would be difficult with manual control.

Incidentally, the Miller Street Substation contains in addition to the two motor-generator-sets a 3000-kv-a. and a 6000-kv-a. transformer bank, two 13,200-volt feeders and three 4150-volt feeders. The ultimate capacity of the substation will consist of five 13,200-volt feeders, two 10,000-kv-a. transformer banks, twelve 4150-volt feeders, and the present two 1500-kw. motor-generator sets including twelve railway feeders with high-speed circuit breakers, all of which will be automatically controlled with the exception of the 13,200-volt feeders. On account of the location of the substation, the motor-generator sets are installed in a soundproof room.(2)

Some Component Parts of the Equipment

Several outstanding features contribute to the simplicity and reliability of automatic railway substations. Among these features is the master switch or motor-driven drum controller, somewhat similar to the familiar drum-type car controller. This directs the sequence of the various functions performed in starting, connecting the machine to the bus, and shutting down. Through its use, correct sequence is assured with the minimum number of interlocks and without the use of auxiliary devices or time-delay relays to govern the sequence. The master switch is the means of centering the control in one reliable device in preference to depending upon several independent devices of less substantial construction.

Synchronous-converter substations include a small single-phase motor-generator set operated only during the starting operation to supply sufficient separate excitation to the converter to establish correct polarity. The use of the small exciter provides a thoroughly reliable means of establishing proper polarity with minimum delay and operations.

The accurate motor-driven time-delay relay that is capable of adjustment over a range of 10 sec. to 35 min. is another important feature. Three of the e relays are usually necessary in an automatic railway substation to determine definite time intervals for preventing starts in case of momentary drops in voltage, preventing shutdown during short no-load periods, and checking the performance of the substation during the starting sequence.

The high-speed circuit breaker, although not a necessity in an automatic substation and not a part of the standard equipment for 600-volt service, is an outstanding development in protective devices available for automatic control. In the past two years, since the new so-called "trip-free" high-speed circuit breakers were made available, a large majority of the automatic substation equipments built included these breakers either in the machine or feeder circuits. The ability of the high-speed circuit breaker to clear short-circuits before the rotating apparatus, the direct-current distribution system, or the rolling stock is damaged, and its ability to discriminate between a short-circuit and a legitimate load render its application to automatic control most important.

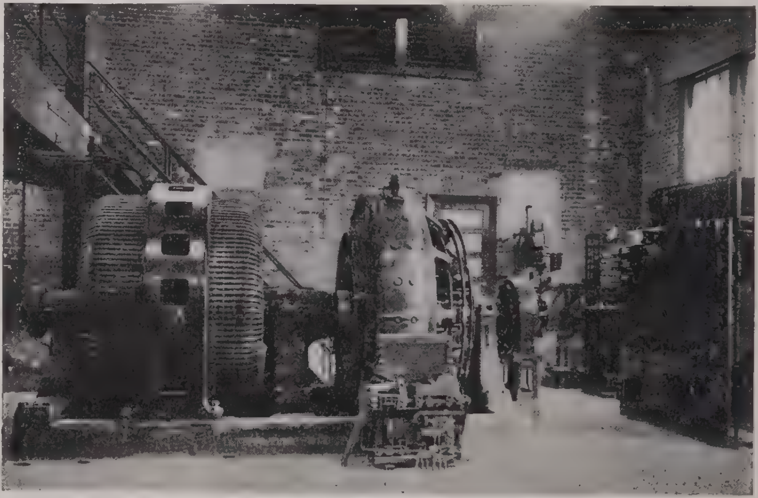

Fig. 5. Interior of 110th Street Station, New York Central Railroad Co., Showing 2000-kw., 666-volt Synchronous Motor-generator Set, High-speed Breaker and Automatic Control Panels

Use of Load-limiting Resistance

In the first automatic substations, protection of feeders was given little consideration because the substations were applied to interurban lines where the trolley and auxiliary feeder was continuous. However, when the success of the automatic substation demanded its application to suburban and city systems, it became necessary to operate and protect individual feeders automatically. This was accomplished first by omitting one of the three usual steps of load-limiting resistance in the machine circuit and applying a similar resistance in each feeder with provision for isolating the feeder in case a short-circuit or overload persisted. This type of feeder protection proved quite satisfactory for interurban and light suburban service; but in heavy service where the resistance between substations is relatively low, the feeder resistance must necessarily be low if the feeder is to continue to deliver a part of the load. Consequently, a short-circuit on any feeder is likely to demand the machine resistance as well as the feeder resistance to limit the current to a safe value, resulting in a complete shutdown of the substation to protect the resistance. It is evident therefore that the feeder equipment for city service should isolate the particular feeder in case of short-circuit as promptly as possible and reclose only when the circuit is clear.

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(2) A more complete description of this substation is given in the article, "Miller Street Automatic Substation of the Public Service Electric & Gas Co. of N. J.," by N. L. Pollard, page 358.—(Ed.)

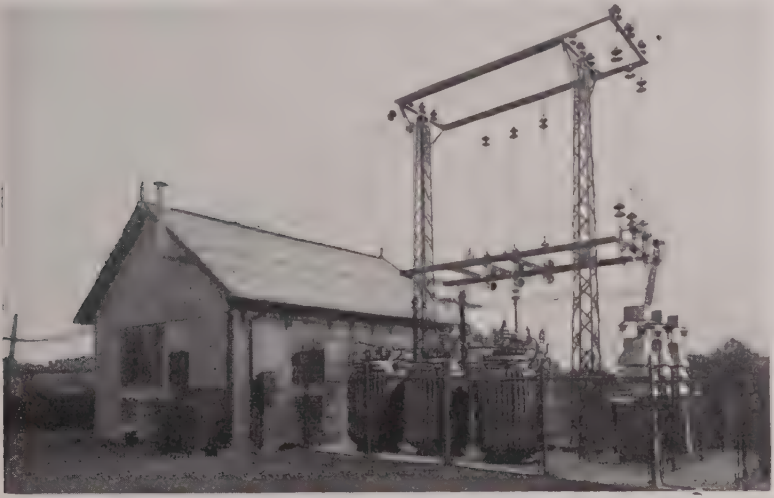

Fig. 6. Automatic Railway Substation of the Detroit Edison Co. at Wolf Hill, Mich., Containing a 1000-kw. Synchronous Converter Set for Feeding the Detroit United Railways

Individual Feeders for Heavy Service

For the heavier service, two types of 600-volt feeders have been developed. These of course are also applicable to interurban systems. A feeder employing the high-speed circuit breaker provides the best protection through its ability to open the feeder circuit so quickly and to discriminate between short-circuit and allowable overloads. After the high-speed circuit breaker is open, the circuit is tested intermittently through a load-indicating resistance; and when the current obtained by testing indicates that the short-circuit has been removed, the high-speed circuit breaker is reclosed.

Another type of feeder employs a latched-in circuit breaker with overload and discriminating features. When the circuit breaker is opened by a short-circuit or overload, a high resistance is inserted to feel out the circuit. A reclosing relay measures the external resistance by means of the load-indicating resistance, and when the conditions permit the contactor is reclosed.

These two types of feeders as well as the load-limiting resistor feeder are arranged to close either from the substation bus or the feeder, depending on which has the higher voltage, thus permitting through feed even though the substation may be inoperative.

Remote Supervision

It is often desirable to have an indication of and to be able to control the operation of automatic substations and feeders from a remote point. To avoid using a large number of wires for this purpose and to eliminate the accompanying disadvantages, supervisory control systems have been developed and are in successful operation for controlling and indicating the operation of several substations and feeders over three or four line wires. Remote indication of power or telemetering is also available.

In addition to the now familiar distributor and selector types of supervisory control, carrier-current supervisory control is available to indicate and operate several substations by using a single line wire.

Increasing Capacity of Installations

The development of the application of automatic railway substations is interesting. The capacity of equipment controlled automatically has been increasing from an average of 435 kw. per unit in 1916 to an average of 1150 kw. per unit in 1924. Automatic control has been developed for and is in operation in 3000-volt main-line electrification service. Numerous 2000-kw. units are installed in automatic substations, and equipment is now being built to control a 3000-kw. motor-generator set for the Georgia Railway & Power Company. To summarize, automatic substations are today in successful operation in every type of railway service.

Changeover of Cleveland Southwestern Railway & Light Company to Automatic Substations

From Company-generated Power to Purchased Power—Installation of Automatic Substation Equipment—Problems in Making Changeover—Scheme of Operation—Light-weight Cars Further Increase Automatic Economies

By G. H. KELSAY, *Chief Electrical Engineer, Cleveland Southwestern Railway & Light Company*
and H. WRAY STINER, *Cleveland Office, General Electric Company*

G. H. Kelsay

DURING the early days of interurban railroading the Southwestern, then known as the Cleveland Southwestern & Columbus Ry. Co., was one of the first to operate out of Cleveland, first to Elyria and the vicinity, then extending south to Wooster and later to Mansfield and Bucyrus where connections are made for Columbus. The Southern Division now forms a link in the chain of interurban electric lines connecting Cincinnati and Cleveland.

Early Generating Stations and Manual Substations

Originally, engine-driven direct-current generators located in several power stations along the system supplied the power. Later, when alternating-current transmission came into use the Southwestern established a central power station at Elyria from which alternating-current power was distributed at 22,000 volts. It was quite natural that this voltage was looked at with considerable awe at that time. Natural gas was used under the boilers for a number of years; however, as this supply diminished and the price increased the boilers were changed over to burn coal.

The Elyria power station contained two 750-h.p., direct-current, engine-driven units, three 1000-kw. and one 5000-kw. alternating-current turbine-driven generators. Two of the 1000-kw. turbines were installed in 1903 and 1904 and had the distinction of being one of the earliest turbine installations for railway service. Transformers stepped the voltage from 400 to 22,000 for transmission to the substations. In 1913, a more modern 2300-volt, 25-cycle turbine generator was installed and tied in with the old equipment on the 22,000-volt bus.

At that time there were 15 manually operated substations and one portable substation containing mainly 300-kw., 650-volt, direct-current, 3-phase, 3-wire motor-started synchronous converters.

H. W. Stiner

Power by Purchase and Automatic Substations

The period following the war placed the Southwestern in somewhat the same condition as many other traction roads in the country. Bus competition and the ever-increasing use of the privately owned automobile made serious inroads into the Company's passenger traffic. The power station was old and consequently in need of extensive repairs. To obtain present-day economy from a station of this capacity meant practically rebuilding it, with considerable new equipment and auxiliaries. The lack of adequate condensing water made the proposition of rebuilding even more expensive. In addition to the power generated for railway use, the Company had assumed from time to time light and power loads which had developed into an important source of revenue and necessitated the consideration of 60-cycle service.

The development of the territory served by the Railway Company would not warrant the building of a power station to compete with central-station power. As a result of these conditions, the decision was made to abandon the power plant and its obsolete generating and auxiliary apparatus and purchase 60-cycle central-station power. This energy is now purchased at Mansfield, Elyria, Penfield, Chestnut, and Berea, metered at

22,000 volts with further arrangements for emergency service from another power company at Berea and Mansfield. Since the 25-cycle transmission lines were for 22,000 volts, it was only necessary to install new oil circuit breakers at feed-in points, these breakers being of suitable rupturing capacity to accommodate the transmission system to the new situation.

The new direct-current system includes 16 railway substations. In making the changeover, advantage was taken of automatic control to eliminate substation attendants wherever possible, thereby effecting a considerable saving in cost of operation. Four of the railway substations are at isolated locations and were made completely automatic, one being a complete new station. Eight substations were made semi-automatic. At six of these a ticket office and freight station is maintained with an agent present during the day. The direct-current equipment of the semi-automatic substations was made automatic, and the direct-current and alternating-current protection carried out much the same as in a full-automatic equipment. The starting or stopping of the machines is done by the station agents. The other two semi-automatic substations are located near the car shops where they receive such attention as is required. The only attention the men give these stations is the routine daily starting and stopping. The substation superintendent and his assistants inspect and maintain both the semi-automatic and the full-automatic stations.

The four remaining substations are manually operated, two being located in car barns, a third at an important switching point on the High-tension Feeder system, and the fourth is a portable substation available for emergency service at any point on the system.

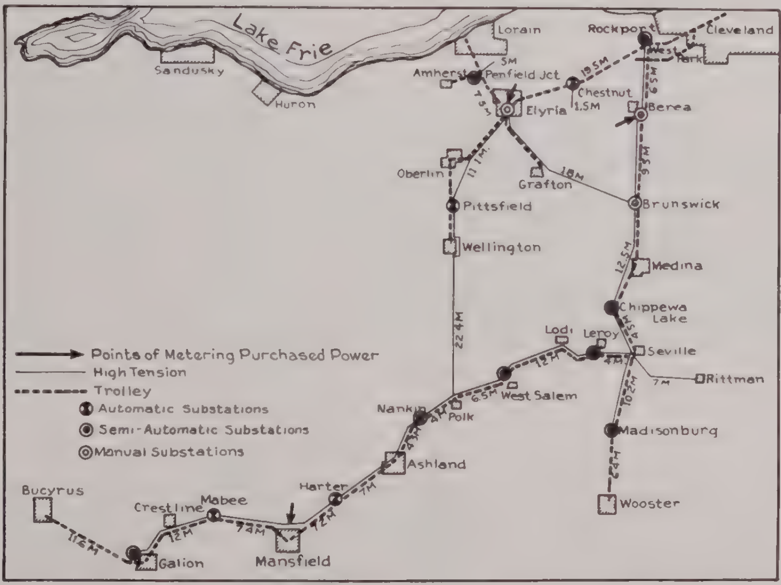

Fig. 1. Map Showing the Territory Served by the Cleveland Southwestern Railway & Light Co., Together with the Locations of Its Purchased Power Feed-in Points and Substations

Automatic Substation Equipment and Operation

The four 325-kw. automatic substations are all alike and in general have standard equipment in which a few changes are incorporated to meet particular conditions. The high-voltage equipment is installed outdoor in an enclosure. Fuses are used for high-voltage protection at each substation. Oil circuit breakers are installed on the secondary side of the transformers for converter protection. All the substations include high-speed circuit breakers for protecting the synchronous converters.

The automatic substations feed directly into the trolley and feeder in front of the substations. The trolley and feeder are sectionalized midway between substations by automatic sectionalizing switches. These substations, as well as the semi-automatic substations, are equipped with load-limiting resistances to protect against abnormal train movement or trolley troubles.

The arrangement of the equipment is such that ready accessibility is obtained and at the same time minimum building space is required. The inside dimensions of the automatic substation buildings are 20 ft. by 14 ft. 8 in. by 14 ft. 6 in., representing approximately 13 cu. ft. per kw.

Fig. 2 is a typical installation of a full-automatic station. Inasmuch as power is obtained at several points, it is possible for most stations to have two sources of supply which can be selected manually by the pole-top disconnecting switches.

The buildings are of concrete block with reinforced concrete roof which has been weatherproofed. Ventilator openings are provided at the bottom and top with an additional opening near the load-limiting resistance. This latter opens directly to the top of the building, thus tending to avoid any trapping of the heated air. A 15-in. I-beam was mounted lengthwise over the converter to facilitate its being dismantled in case of necessity. Fig. 3 shows the converter as seen from the station door. An old car compressor was installed to furnish air for cleaning. Fig. 4 shows the automatic control panel, the general arrangement of the load-limiting resistors, the mounting of the contactors, and the location of the high-speed circuit breaker.

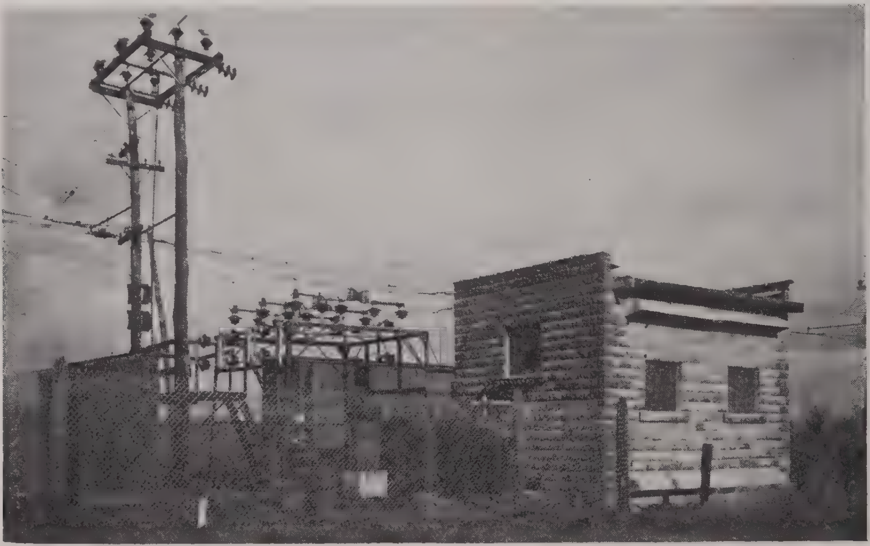

Fig. 2. Harters Substation, Containing One 325-kw., 650-volt, 60-cycle Synchronous Converter and Its Automatic Control Apparatus. The remainder of the equipment is located outdoor within the wire enclosure

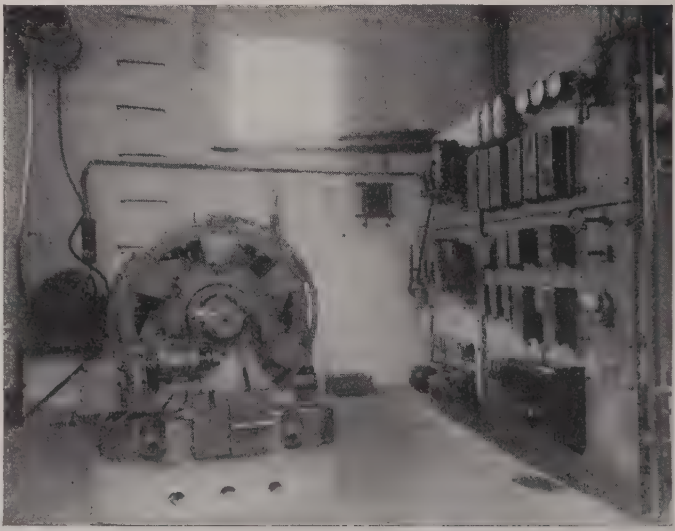

Fig. 3. An Interior View of the Harters Substation, Showing the Converter and Switchboard

Problems Involved in the Changeover

The Southwestern operates 194 miles of interurban railway and furnishes light and power for 36 cities and villages in addition to many miles of rural service. The change to 60-cycle service presented many problems. Franchises had to be modified and hundreds of motors had to be rewound or exchanged with maintenance of continuous service. It required approximately a year to complete the entire change.

The changeover of the Railway substations without interrupting service presented an interesting problem. Nearly all the old transformers could be used on 60 cycles, as the 25-cycle reactance was sufficiently low to permit operation on 60-cycle service, the core loss at 60 cycles was slightly lower than the 25-cycle core loss. A three-phase auto-transformer was installed to obtain the increase in collector-ring voltage required for 6-phase, 60-cycle operation over that of 3-phase, 25-cycle operation. The use of the auto-transformer solved the problem of securing proper voltage from the old transformers and provided a 50 per cent starting tap. It was therefore not necessary to raise the transmission voltage or disturb the old transformers in any way, and not having to raise the transmission voltage left the light and power voltage situation undisturbed.

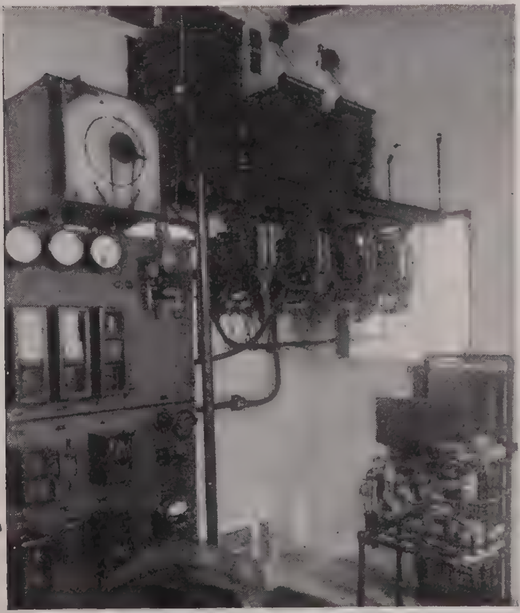
Fig. 4. Another View Within the Harters Substation, Showing the Automatic Switching Panels, High-speed Circuit Breaker, and Load-limiting Resistances

The power rate of the central station made a good power-factor highly desirable, and as a consequence a special design of compound-wound converter was used. The series field was provided with a shunt which gave a series field strength of about 25 per cent of the usual value. In this way the converters are operated at unity power-factor or slightly better at light load and with leading power-factor under load conditions. Thus, the converters are utilized to obtain a good average power-factor on the system. The average power-factor for the entire load has been from 90 to 93, which is very good considering that about 45 per cent of the load consists of the Railway Company's light and power business.

Inasmuch as the old converters were operated at 650 volts, the new converters were built for normal operation at the same voltage. This change in design to obtain the increased voltage resulted in a converter rating of 325 kw. for the current rating of the standard 300-kw. converter was maintained.

New Light-weight Cars

As a further step in reducing operating costs and improving service, the Company recently put into operation on the Western Division twelve light-weight interurban cars which effected a substantial saving in power consumption and maintenance. These lighter cars weigh 17 tons, seat 52 passengers, and were built by the Cincinnati Car Company. They are equipped with four, GE265, 35-h.p. motors, geared for 45 m.p.h. and single-end type "K" control. The cars replaced weighed approximately 37 tons and were equipped with four 90-h.p. motors. The service was increased with the new cars, giving 30-min. service out of Cleveland on the Western Division. Together with the automatic supply of power, these cars have materially improved the service offered the traveling public and make competition with buses more effective.

Periodic and thorough inspections are essential to the maximum life and best performance of any type of machinery

Automatic Switching Equipment Devices

Classification—Motor Mechanisms for Oil Circuit Breakers—Relays: Grounding Protective—Hesitating Drop-out—Sensitive Voltage and Current—A-c. Differential—D-c. Directional—Thermal and Temperature—Timers

By R. M. Brockway

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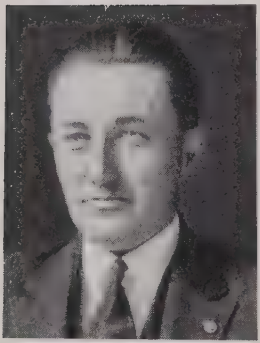

R. M. Brockway

THE successful operation of an automatic switching installation depends not only upon the correctness of the scheme of control but also upon the proper functioning of the devices which form the equipment. A perfect plan of connections is of no avail if the devices cannot be relied upon. Because of this vital fact, each device designed for automatic station service is thoroughly tested, including life test, before being put in production; and each device manufactured is tested individually and as a part of the complete automatic equipment.

The devices used include many types and sizes covering a wide range of characteristics. Many were standard with manual equipments before being adopted for use with automatic control, while others were developed to meet particular requirements of automatic equipments. This article will deal principally with devices of the latter class.

Automatic station devices may be classified as follows:

(1) Line circuit interrupting devices: Air circuit breakers, oil circuit breakers, direct-current contactors, alternating-current contactors.

(2) Mechanisms: Motor or solenoid mechanisms for operating air or oil circuit breakers, motor-driven brush-operating mechanisms for synchronous converters.

(3) Control and auxiliary contactors: Small alternating-current operated or direct-current operated contactors with from one to eight contact circuits.

(4) Relays:
    Overcurrent: direct-current plunger types, alternating-current induction or plunger types, alternating-current—direct-current grounding protective relay.
    Sensitive alternating-current undervoltage relay.
    Hesitating drop-out relays.
    Sensitive voltage or current relays.
    Alternating-current differential relays.
    Direct-current directional relays.
    Thermal or temperature relays.
    Timers.
    Auxiliary: Plunger and hinged-armature type relays.

(5) Miscellaneous: Motor-driven master switches, float switches, time switches, pressure switches.

The majority of these listed devices do not require further explanation. Description will therefore be confined to a few of the others which were specially designed for automatic station applications.

Motor Mechanisms for Oil Circuit Breakers

Fig. 1 shows a motor mechanism which can operate any of the panel-mounted oil circuit breakers (i.e., breakers up to 800 amp., 15,000 volts). A larger mechanism of the same type is capable of operating the large frame-mounted oil circuit breakers up to 600 amp. 154,000 volts. These mechanisms are used with the automatically controlled breakers of alternating-current reclosing feeders and of some types of automatic stations.

The principal parts of the mechanism are the auxiliary relay, motor, centrifugal mechanism, counterweight, auxiliary switches, and tripping mechanism.

A small hinged-armature-type auxiliary relay is provided to close the motor circuit so that the mechanism can be controlled by light relay contacts. The motor has a series characteristic and may be operated from either a 220-volt 60-cycle alternating-current or 125-volt direct-current source. The alternating-current power required by the motor to close a breaker is so small that it can be supplied by a 1½-kv-a. transformer. The motor shaft is attached to the lower junction of the four links shown directly above the motor, in a position corresponding to a closed breaker. When the breaker is open, the long diagonal of the figure formed by the links is vertical instead of horizontal. The links revolve with the motor shaft. As the motor speed increases, the centrifugal force acting on the small weights at the outer ends of the links becomes great, the weights are forced outward, and the upper ends of the links drawn down until they assume the position shown. This causes the outer heavy end of the counterweight to be thrown upward and inward to the position shown at the top of Fig. 1. The link attached to the counterweight is thrust to the rear and closes the breaker. When the mechanism reaches the closed position, an auxiliary switch at the right of the counterweight opens the motor circuit. The auxiliary switch at the left, usually connected in a potential trip-coil circuit, closes. The motor armature and weights spin freely until they come to rest.

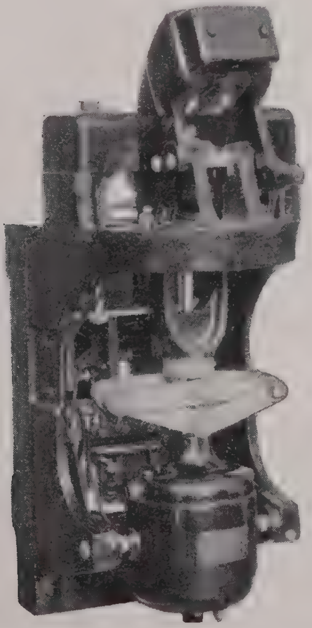

Fig. 1. Motor Mechanism for Operating Oil Circuit Breaker (cover removed)

The combined characteristic of the motor and centrifugal mechanism is such that a very large force is available.

In the upper rear part of the mechanism there is a trip lever with provision for operation by any number of current or potential trip coils up to a total of four. When the trip lever unlatches the toggle holding the breaker closed, the breaker opens and the mechanism is returned to the starting position by the falling of the counterweight.

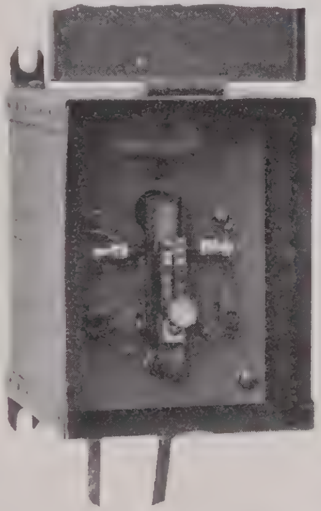

Fig. 2. Grounding Protective Relay

The larger mechanism of this type has a motor of correspondingly larger size and a separate auxiliary relay or contactor. One model of motor is used for 220-volt 60-cycle alternating-current or 125-volt direct-current operation and another model for 24-volt direct-current operation.

Grounding Protective Relay

Certain classes of power apparatus in automatic substations must be protected against the effects of grounded windings. The relay used for this service has proved so successful that it has been adopted as standard equipment for some sizes of machines used in manually controlled substations.

The complete device, shown in Fig. 2, consists of a simple hinged-armature-type hand-reset overcurrent relay mounted on a small slate base and placed in a sheet-metal enclosing case. The case has a hinged cover to permit inspection and feet for bolting to the base or frame of the protected apparatus The frame must be insulated from ground

The relay coil consists of a few turns of No. 00 insulated copper wire with long connection leads. The coil is connected between the frame of the protected apparatus and ground so that any appreciable flow of current from windings to ground will operate the relay. The calibrating plate has a direct-current scale marked 40-65-100 amp. and a 60-cycle alternating-current scale marked 50-90-130 amp. The action of the relay is very fast and when set at the minimum calibration it will operate and disconnect the protected apparatus before the ground current can cause serious damage. Notwithstanding its low operating point, momentary coil currents of 10,000 amp. will not injure the relay.

The relay has hand-reset contacts for controlling two independent circuits. The contacts are so designed that either or both contact circuits may be quickly and easily changed from circuit opening to circuit closing or vice versa without tools, by hand. The contacts are so connected to control circuits that the operation of the relay causes the protected apparatus to be disconnected from its load, its power supply, or both.

Hesitating Drop-out Relays

A hesitating drop-out relay used as a synchronous-speed device and as a field relay with certain types of automatic equipments is shown in Fig. 3.

The lower part of the relay contains the coil, the relay plunger in the center of the coil, and a heavy stationary copper sleeve surrounding the plunger. The upper part of the plunger actuates the toggle-type contact mechanism. One of the two independent contact circuits closes and the other opens when the relay is energized. The bottom of the plunger carries a weight-box for holding the shot used to vary the pick-up point of the relay. If it is desired to obtain the minimum pick-up without means of adjustment, the weight-box can be removed by taking out a cotter pin.

The copper sleeve about the plunger causes a large retardation or damping of all flux changes due to changes of coil current and gives the relay two desirable characteristics. The first of these is its time delay of one second or more on drop-out and failure to drop-out on momentary dips in coil current. The second is its inability to pick-up on alternating current. The first characteristic makes the relay desirable for use as a field relay with its coil in series with the fields of synchronous motors or converters, especially the latter where sudden load changes cause momentary changes of field current. The second characteristic makes the relay suitable for use as a synchronous-speed indicating device for synchronous motors and converters. When the coil is connected across a synchronous-converter armature or in series with a synchronous-motor field, the relay is subjected to alternating or pulsating direct current while the machine is starting and will not pick-up until the frequency of the direct-current pulsations has become very low. This means that the relay picks up approximately at synchronism.

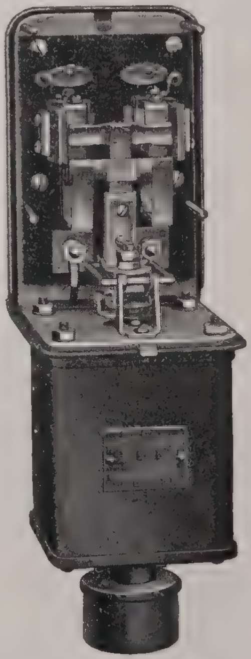

Fig. 3. Hesitating Relay (cover removed)

The pick-up without the weight-box is fixed at 40 per cent or less of the coil rating. With the weight-box, the pick-up is adjustable upward from about 50 per cent of the coil rating. The drop-out point is low.

A relay in the same frame and case and with the same principle of operation, but with a single heavy circuit closing contact with blowout coil, is used as a hesitating solenoid control relay with direct-current solenoid-operated circuit breakers.

Sensitive Voltage and Current Relays

Fig. 4 shows a relay typical of a group which, because of wide range of adjustment, has many applications in automatic equipments.

As shown in the illustration, the core of the coil is under one end of a pivoted armature to which is attached a spring which pulls the armature upward against the magnetic attraction of the core. The ends of the armature carry contacts which, with the two stationary contacts above, form two independent contact circuits. When the relay is de-energized, one circuit is closed and the other is open.

There is a screw adjustment for changing the position of the core in the coil. The leverage of the spring on the armature may be changed by hooking the spring into different holes in the two bars shown at the ends of the spring. The contact gap may be changed by screwing the stationary contacts up or down. By means of these three adjustments the typical direct-current voltage relay shown in Fig. 4 may be made to have either snap action (quick movement of the contacts when the voltage reaches a certain value), or float action (slow movement of the contacts first opening one circuit and later closing the other when the voltage further changes). With snap action, the pick-up (operation on rising voltage) and drop-out (operation on falling voltage) may be adjusted over a very large range. The difference between pick-up and drop-out may be varied between wide limits. With float action, the voltage change between the opening of one contact and the closing of the other is adjustable.

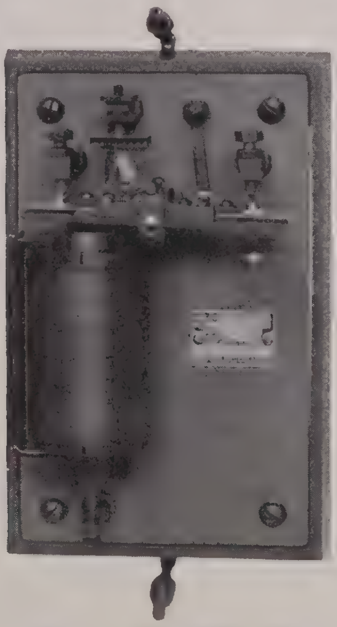

Fig. 4. Sensitive Voltage Relay

There are several modifications by which a whole group of relays may be derived from the voltage relay of Fig. 4. The relay may have either a direct-current or an alternating-current voltage or current coil, a combination coil with both voltage and current windings, or a coil with two or more voltage or current sections. The operation on alternating current is about the same as on direct current, with the exception that the relay is not adjusted for floating contact action. A small oil dashpot may be added at the right end of the armature to give damping action or a few seconds time delay on pick-up and dropout. By adding a second coil and core under the right end of the armature a relay is obtained which may be used to balance the actions of direct-current voltages or currents against each other. Such a relay can be adjusted to operate on unbalances as low as 2 per cent of the normal rating of one of the two balanced circuits. Another form of the relay is mounted with the long dimension horizontal and has a long calibrating arm with sliding weight attached to the armature so that the two form a "T" with the long horizontal member. This type has quite different characteristics and is used as a voltage equalizing relay with some direct-current automatic reclosing equipments.

Owing to the wide range of adjustment which can be obtained with these relays, they are used for special applications requiring unusual settings which cannot be obtained with the ordinary types of relays. They are also used with various standard automatic equipments as master starting element (to give starting indication of direct-current undervoltage or overcurrent), alternating-current undervoltage relay, alternating-current overvoltage relay, alternating-current undercurrent relay, direct-current undervoltage relay, direct-current reclosing relay, current regulating relay, and direct-current voltage equalizing relay.

Alternating-current Differential Relays

A differential-frequency relay used as a synchronous-speed device with one type of synchronous motor-generator equipment is shown in Fig. 5.

This device consists of two induction disk elements mounted on a common shaft which actuates the contact mechanism. There are two coils associated with each disk. One is an inductive coil connected directly across a source of alternating-current potential and the other is connected to the same source in series with a condenser. The torques due to the two coils oppose each other and the magnets can be adjusted to balance the torques at a predetermined frequency. A decrease of frequency will then cause rotation of the disk in one direction, and an increase of frequency will cause rotation in the other direction. The coils associated with one disk are energized from the line supplying the motor-generator, while the coils with the other disk are energized from slip rings on the exciter of the motor-generator. The exciter frequency is a measure of the speed of the motor-generator. The two sets of coils are so placed relative to the disks that increasing line frequency tends to rotate the relay shaft in one direction, while increasing exciter frequency tends to rotate the shaft in the opposite direction. Thus the shaft rotates only with a change in the difference between line frequency and exciter frequency, i.e., change of slip. With standard equipments the relay is usually adjusted to close one set of contacts at approximately 93 per cent synchronous speed and to close the other set of contacts at approximately 95 per cent synchronous speed, with any ordinary variations of line voltage and frequency or exciter voltage. The contacts are for two independent circuits.

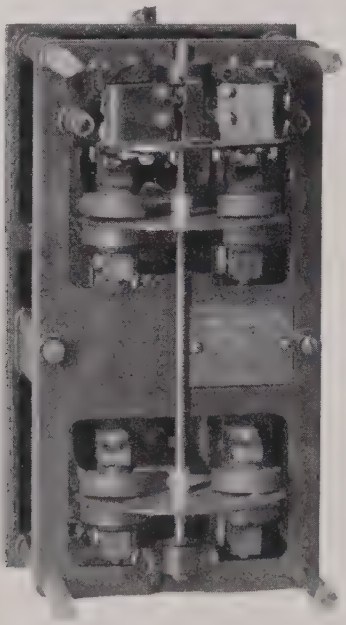

Fig. 5. Differential-frequency Relay

An induction-type phase-balance current relay is used to protect equipments against failure of line current in any phase or heavy current unbalance. The relay is similar in appearance to the one shown in Fig. 5, except that it has three induction-disk elements. The three elements are mechanically independent and each balances the currents of two phases against each other and closes an independent set of contacts when the two currents become unbalanced. The relay has six current coils, two in each phase, with each of the two coils in any one phase operating on different disks, and so connected that the current of each phase is independently balanced against the currents of each of the other two phases.

Direct-current Directional Relays

Direct-current directional relays have characteristics which enable them to perform several important functions in automatic equipments.

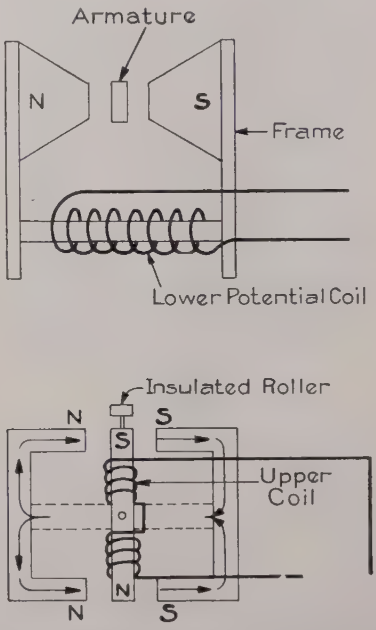

Fig. 6. Magnetic Circuits of Direct-current Directional Relay

A typical relay of this class is shown schematically in Fig. 6. The upper part of the illustration is a front view, and the lower part a top view. The lower coil is connected to a constant-potential source and magnetizes the frame as indicated by the letters *N* and *S*. An armature, pivoted at the center, lies between the pole pieces forming the upper part of the frame, and is magnetized by the upper coil. The movement of the armature depends upon the magnitude and direction of its magnetic field relative to the magnitude and direction of the magnetic field of the pole pieces, i.e., movement depends upon the relative magnitudes and directions of the currents in the upper and lower coils. The movement may be modified by springs. The insulated roller on the end of the armature operates contacts. An independent pair of contacts may be placed on each side of the armature and each pair may be made either circuit-opening or circuit-closing when the armature swings toward it.

Various forms of relays of this general character are made possible by combinations of different coils, springs, and contact arrangements.

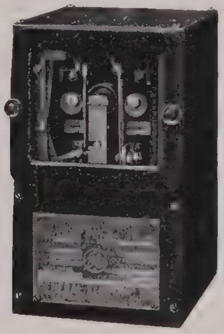

Fig. 7. Direct-current Reverse-power and Underload Relay

One form is the sensitive direct-current reverse-power and underload relay shown in Fig. 7. The lower coil is connected across the armature of the protected machine and the upper coil takes from a copper shunt a current proportional to the machine load. When the load increases, the relay armature swings to one side and closes the load contacts. If load decreases below a predetermined point, the armature swings back toward the center position and allows the load contacts to open. This underload operation is adjustable down to 3½ per cent of the maximum circuit or machine rating. On reverse power, the armature swings to the other side and opens the reverse-power contacts. The reverse-power operation is adjustable down to 1½ per cent of the maximum circuit rating.

If the lower potential coil of the relay in Fig. 6 is replaced by a permanent magnet and the upper coil is connected across a direct-current generator armature, there results a polarized relay which will determine whether the generator polarity is correct. This relay closes its contacts on voltages of correct polarity between 40 and 65 per cent of normal.

When used as a direct-current reclosing relay, the lower coil is connected across the source of power and the upper potential coil is connected across the feeder load. Thus the relay measures load resistance and can be set to close its contacts when the resistance rises to any predetermined value within the operating range. The calibrating scale is marked in terms of the load current which will flow after the feeder recloses The usual scale is from 0.25 to 1.0 times the rated feeder current.

When used as a direct-current voltage-directional relay the upper coil is connected across the line contactor or circuit breaker, and the lower coil across the source of direct-current voltage (machine or bus). When the line breaker is open the relay will not close its contacts until the voltage across the breaker is in a predetermined direction relative to the voltage of the source, and has risen to the value for which the relay is calibrated (usually 2 per cent of normal voltage). With this arrangement the relay contacts may be used to control the closing of a breaker or to insure the connection of a direct-current control bus to the higher voltage side of a breaker through which power may feed in either direction. If there are breakers in both sides of the line, the upper relay coil is made in two sections and one section is connected across each breaker.

With some equipments, this type of device is used as a current balance relay to insure approximately equal division of load between two direct-current generators operating in parallel. The lower potential coil is connected across the bus. The upper coil is divided into two sections with one section in parallel with the commutating field of each generator. The two sections are so connected that their magnetic fields oppose each other. The relay armature then swings from the center position only when one coil overpowers the other, i.e., only when the generators divide the load unequally. There are two sets of contacts by means of which the generator-field-rheostat resistances are changed. This relay can be adjusted to hold the load unbalance to less than 10 per cent.

Thermal and Temperature Relays

This class of relays includes alternating-current thermal relays, bearing-temperature relays, thermostats, and contact-making temperature indicators.

The alternating-current thermal relays operate from current in the secondaries of current transformers in the alternating-current line to the protected machine. An auto-transformer in the relay steps up the current to the value required for efficient operation of the heating element, which consists of a heater and thermostatic metal strip in series. The heater is surrounded by a thermal storage block from which heat is transmitted to the strip. In addition, on heavy overloads, the thermostatic metal strip is heated directly by the passage of current through it. The movement of the thermostatic metal strip as it is heated and cooled operates contacts which cause the protected machine to be disconnected from its load when its temperature approaches a critical value and to be reconnected after it has cooled. The time-current curve of the relay depends on the proportions of the storage block and thermostatic metal strip. It is designed to protect the average machine of the class for which it is used with a factor of safety to cover variations of individual machines. The relay automatically compensates for changes of ambient temperature.

Bearing temperature relays which depend upon expansion of the contents of a bulb placed in the bearing, thermostats, and contact-making temperature indicators require no description.

Timers

There are two principal timing relays used with automatic switching equipments. One is a squirrel-cage induction-motor-driven definite-time relay, and the other an induction-disk motor device used to control and time the operation of oil circuit breakers of alternating-current reclosing equipments.

The definite-time relay is shown in Fig. 8. A small single-phase alternating-current squirrel-cage motor in the base of the relay drives a planetary gear mechanism which operates the contacts. By shifting a small lever to one of four positions the gear system can be made to give any one of four gear ratios. The dial and pointer used for finer time adjustment gives 21 time settings for each ratio. Moving the scale pointer changes the time by changing the distance through which the planetary gear system must move to trip the contacts. The total time range is approximately 2½ sec. to 30 min. for a 60-cycle relay and approximately 10 sec. to 140 min. for a 25-cycle relay. The time delays for various lever and scale settings are tabulated on the relay index plate. The time is inversely proportional to the frequency but is not appreciably affected by changes of operating voltage or temperature.

The alternating-current holding coils shown at the top in Fig. 8 actuate a pawl mechanism which allows the motor to drive the gear system. The relay times only when the holding and motor coil circuits are closed. If the holding and motor coils, or the holding coils only, are de-energized before the timing operation is completed, the mechanism resets to the starting position. If the motor is de-energized but the holding coils left energized the mechanism stops timing but does not reset, and the elapsed time to the point where the motor stopped is counted when the motor starts again. At the end of the timing operation the contacts are tripped and remain in the tripped position as long as the holding coils are energized. The motor circuit should be opened when the contacts trip. When the holding coils are de-energized, the contacts and mechanism reset to the starting position. The contacts are circuit-opening and circuit-closing for two independent circuits. The holding coils and motor together require about 50 volt-amperes for operation.

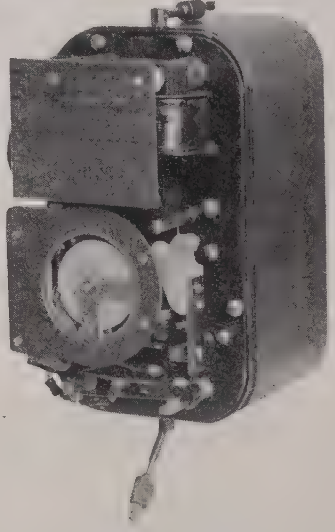

Fig. 8. Motor-driven Definite-time Relay (cover removed)

The timer used as an alternating-current reclosing relay is shown in Fig. 9. It consists of an induction-disk motor, partly shown in the lower part of the illustration, which through gearing drives three arms which operate the contacts in the upper end of the relay. There are also a release magnet, shown in the middle of the illustration, and an auxiliary relay hidden behind the front plate. The release magnet and auxiliary relay may have either alternating-current or direct-current coils.

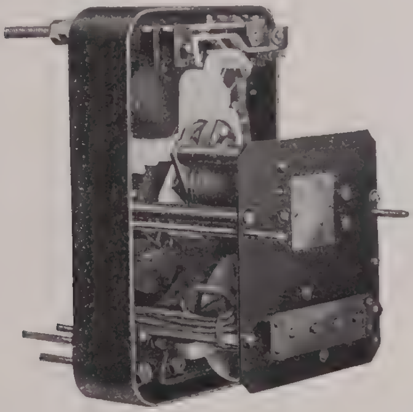

Fig. 9. Motor-operated Timing Relay (cover removed)

The timer is used as a reclosing relay with one oil circuit breaker. The release and auxiliary coils are connected to the control power source through an auxiliary switch on the circuit breaker. The motor coils are continuously energized from an alternating-current supply, but the motor can be started only by energizing the release coil (opening the breaker). Once started, the motor operates through a complete cycle, and rotates the three arms past the contacts. As the first arm passes, it closes in succession the two contacts which with the auxiliary relay form a closing circuit for controlling the circuit breaker. The operation is repeated as the second and third arms pass, and thus the breaker is reclosed a second or a third time if the overload condition which causes it to trip persists. If the release is de-energized (breaker closed) as the timer completes its cycle, the mechanism is stopped in position ready to start a new cycle. If the release is energized (breaker open) as the cycle ends, a lock-out stop prevents further operation until the timer is reset to normal condition by de-energizing the release and depressing the external hand-reset lever.

The time of a cycle for the standard timer is 2½ min., with adjustment from 2 min. minimum to 3 min. maximum. The arms can be easily shifted to give any desired intervals between reclosures, provided the interval is 5 sec. or more. Special timers with different gear ratios can be supplied to give longer cycles of operation.

Conclusion

Thus there is available to the designer of automatic switching equipment a wide variety of devices, some of which were initially developed and exclusively used for the manual control of switching operations and the remainder are of later origin, these being developed specially for automatic controls to fill those particular functions for which no equally suitable manual control device had been standardized. Although many in number, they may be readily classified into groups or families according to their fundamental characteristics of operation. Among the members of each family there is then available for selection some device with that variation of the distinct characteristic which is needed for the solution of the particular control problem confronting the designer. The use of these fully tested and standardized devices has been shown by long experience to result in thoroughly dependable automatic switching operations with the minimum expenditure of time and money to maintain continuously a very high grade of service.

Supervisory Systems

Necessity for Unified System of Control—The Telephone—Superiority of Automatic Supervisory Equipments—The Distributor System—Cable System—Selector System—Carrier-current Selector System

By C. E. Stewart

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C. E. Stewart

The economical distribution of power in large cities requires the use of a number of substations each located at an individual load center. These substations serve as a connection between the high-tension transmission system and the many circuits which supply energy to the consumer at commercial voltages.

The successful operation of such a system depends upon an overall human intelligence to direct its energy flow. Therefore, load dispatchers or system operators are located at one or more points in the power system network. It is thus evident that, for unit operation, the load dispatcher must require and have recorded in his office a vast amount of knowledge concerning the individual circuits under his jurisdiction.

During the past ten years the automatic generating station and substation have become vital factors in the electrical power industry, and where used they have had a considerable influence in improving the art of load dispatching. In addition to eliminating the dispatcher's dependence upon the human element, they have given rise to the development of new and better channels through which he can conduct his supervision. When automatic switching equipment is employed in place of manually operated equipment to furnish better service or to secure greater economy, the absence of an operator prevents the dispatcher from making use of the telephone for issuing orders as to the operation of the circuits and for receiving information as to their condition. This circumstance as much as any other has created a demand for an equipment which will automatically give the load dispatcher visual indication of the condition of his power equipment. At the same time it must provide him with a means of controlling this power apparatus. An equipment which provides these requirements is called a supervisory system.

However, the lack of telephone communication between the dispatcher's office and the automatic station is not the only reason for the use of a supervisory system. Such a system permits a wider application of the automatic station because the dispatcher has supervision over the station when abnormal conditions occur. The automatic station equipment protects itself during starting, running and stopping operations. However, there are certain emergency conditions over which the station equipment has no control. This might be illustrated by the case of a fire in a certain section of the city where the electrical circuits are supplied from an automatic station. In this case it is necessary for the dispatcher to open feeder circuits supplying this district.

The use of telephony for the transmission of operating orders divides the responsibility and very often leads to costly errors. In cases of emergency, the telephone is also relatively slow for the transmission of orders. The supervisory system provides a direct and speedy method by which the dispatcher can perform his own operations and he is automatically advised of any change in his system set-up.

A supervisory system besides making a saving in operating expense, provides a means whereby a power system can be operated as a unit. Unit operation of installed power equipment assures the maximum operating efficiency.

Continuity of power supply is extremely important. The application of a supervisory system to the automatic substation is therefore valuable because it notifies the dispatcher immediately when trouble occurs. No time is lost in sending maintenance men to the station in case some protective relay has shut the station down or in case a feeder breaker has been locked out by its automatic equipment.

Where there are several miles between the dispatcher's office and the outlying station it is obvious that any supervisory system to be economical must operate over a very few wires between the two stations.

To fulfill the requirements of operating companies, the following modern systems are available.

Distributor Supervisory System: This system is applied to the supervision of stations which contain a large number of power units located at considerable distances from the dispatcher's office. Four line wires are required between stations for controlling and indicating units of 50 oil circuit breakers or less.

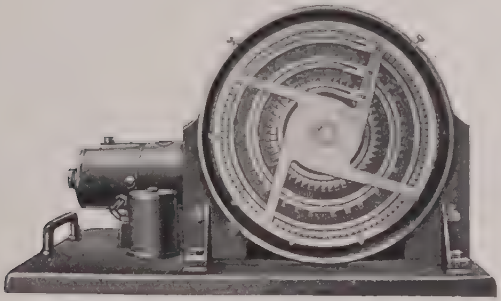


Fig. 1. Synchronous Motor-driven Contactor for Distributor Type Supervisory System

Cable Supervisory System: This system finds its application where the distance between stations is short and where it is practical to install multiple-conductor lead-covered cable between the dispatcher's office and the substation.

Selector Supervisory System: This system is designed to supervise a few units in each of a number of outlying stations. It will operate over three wires, running continuously from the dispatcher's office through all outlying stations.

Carrier-Current Selector Supervisory System: This system may be applied where the expense of installing three line wires between stations is prohibitive, or where open wire construction would parallel the high-tension transmission system. Supervision may be accomplished over a single circuit, an existing open wire telephone circuit, and in many cases over the transmission system itself.

All of the foregoing systems receive their operating potential from storage batteries. This insures their energy supply in case of failure of the main power circuit.

Distributor Supervisory System

The distributor supervisory system has been developed from equipment used successfully in the printing telegraph service.

Fig. 1 shows a distributor, which is the operating part of the system. It consists of a 1/50-h.p., 120-volt direct-current motor equipped with a speed regulator. Through reduction gears and a friction clutch this motor drives a brush carriage on which three brushes are mounted. As these brushes are rotated they each momentarily complete an electrical circuit between a large number of segments and separate collector rings.

Two distributors are required, one located in the dispatcher's office and one in the outlying station. The function of the pair of distributors is to reduce to a minimum the number of line wires required between stations. These conductors have been reduced to four in number and consist of the control, indicating, synchronizing, and common return wires. Generally, No. 19 or 22 B.&S. wire in lead-covered cable meets all operating requirements. In some installations two pairs of wires are rented from a telephone company.

In the dispatcher's office those segments associated with the inner collector ring are each connected to individual two-position control keys. The outer segments are each connected to a two-position polarized relay. The position of this relay determines whether the red- or the green-capped indicating lamp is lighted.

At the substation those segments associated with the control wire connect to two-position polarized relays. The position of the polarized relay in this case determines the closing or tripping operation of the oil circuit breaker. The segments associated with the indicating wire are connected to interlocks on the oil circuit breaker.

The principle of operation requires the synchronous rotation of the two distributor brush arms. This is accomplished by using the synchronizing line wire and the middle set of short segments on the face of the distributor. Through this circuit, release magnets on both distributors are operated in series. Unless these release magnets are energized they engage with lugs on the brush carriage and prevent its rotation. If now one brush carriage tends to run faster than the other, it will be held until the other catches up with it. At this point both sets of brushes will be in exact synchronism and will be released together. This check-up and correction is made every half second. Both brush arms thus rotate in synchronism at a speed of one revolution every five seconds.

In effect these distributors serve to make momentary contact between any particular control key in the dispatcher's office and its corresponding polarized control relay in the substation. A momentary circuit is also made from interlocks on the oil circuit breaker over the indicating wire to a polarized relay which controls a pair of indicating lamps in the dispatcher's office. The pair of distributors rotate continuously and connect both the control wire and indicating wire to 50 individual circuits during one revolution of the brush arms.

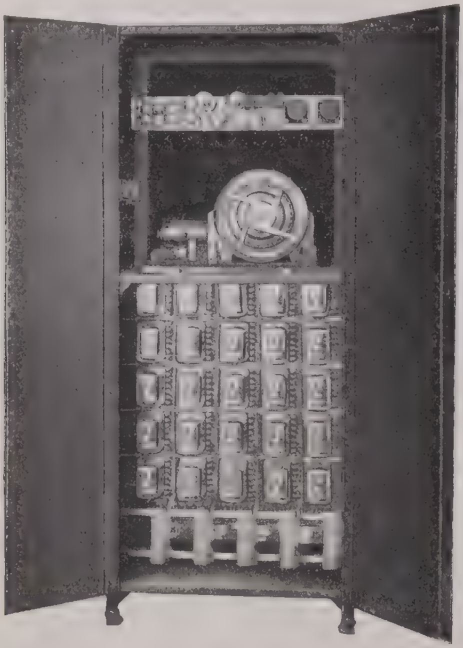


Fig. 2. Distributor and Relay Cabinet, Distributor Supervisory System

Fig. 2 shows a distributor and relay cabinet used both in the dispatcher's office and substation. This cabinet contains the distributor and 50 polarized relays. It is of sheet-metal construction equipped with front and rear hinged doors, and is completely wired with all terminals for external connections placed in the bottom of the cabinet. The cabinet stands 75 in. high and requires a floor space of 18 by 30 in. All the relays are of rugged construction and have large contacts and dustproof covers.

All electrical circuits between the distributor and relays in the cabinet are made by means of multiple-jack connections. It therefore can be easily removed and a spare distributor inserted in its place should inspection or repair make this necessary.

Fig. 3 shows a dispatcher's control and indicating panel, containing 50 individual key and lamp units. This panel is of steel construction and designed for floor mounting. It is completely wired and all external connections are brought to standard terminal blocks in the sub-base of the panel. This panel is 60-in. high, 21½-in. wide and 6 in. deep. Each individual unit consists of a two-position key, red-, green- and white-capped indicating lamps, and a designation strip.

A master operating key, a bell key, and indicating lamps common to the system are also mounted in this cabinet. The use of a master operating key prevents a false operation due to the accidental turning of one of the control keys. No control operation can be performed unless the master key is also turned. When once turned, this key automatically returns to the "off" position after the control impulse has been sent out.

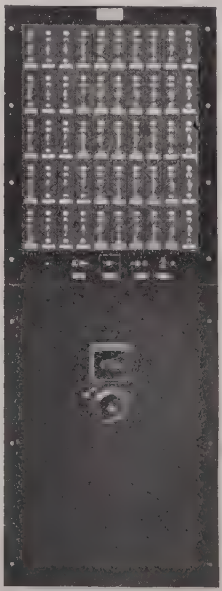


Fig. 3. Dispatcher's Key and Lamp Panel, Distributor Type System

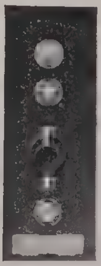


Fig. 3a. Key and Lamp Unit Removed from Panel

Assume now that the dispatcher wishes to close a certain oil circuit breaker in the outlying station. The green indicating lamp shows that the breaker is open. He will turn the key corresponding to that breaker and the white-capped lamp associated with that unit then lights. He will then turn the master control key. This makes possible the momentary electrical circuit between the stations, as the distributor brushes pass over the associated segments. The corresponding control relay at the substation is thus thrown to make one of its electrical circuits, which through auxiliary devices closes the oil circuit breaker.

A polarity impulse originating from interlocks on the breaker is in a similar manner sent back over the indicating wire. The associated polarized relay in the dispatcher's office is thrown to light the red-capped lamp. At the same moment the green- and white-capped lamps are both extinguished and an alarm bell rings. Depending upon the position of the bell key, this alarm will be either a single stroke or a continuous ringing until turned off by the dispatcher.

Any number of control keys can be turned at one time and all operations will be completed within a maximum time of five seconds after turning the master key. Indication of the new position of supervised apparatus will be registered on the indicating lamps within an additional five seconds.

The position of all supervised equipment is checked every five seconds. It is evident then that if an oil circuit breaker trips out, due to an overload on its circuit, the dispatcher is notified of this fact within a maximum time of five seconds. A bell rings to call his attention to the change and the individual white-capped lamp associated with that breaker lights. This enables him to determine what circuits have changed position.

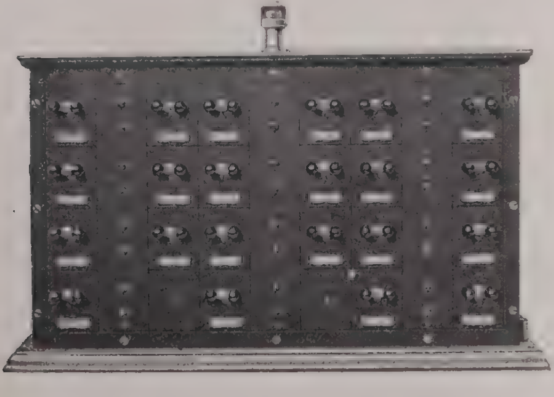


Fig. 4. Dispatcher's Key and Lamp Cabinet, Selector Type Supervisory System

In the design of this equipment all possible features have been incorporated to notify the dispatcher in case of trouble on the system. For example, if the speed of the driving motor on one distributor becomes slower than that of the motor on the other, this condition is immediately made apparent to the dispatcher by a red light and a gong. In the majority of cases, he is also notified when common operating troubles occur such as open-circuits, short-circuits, or foreign potentials on the line wires between stations.

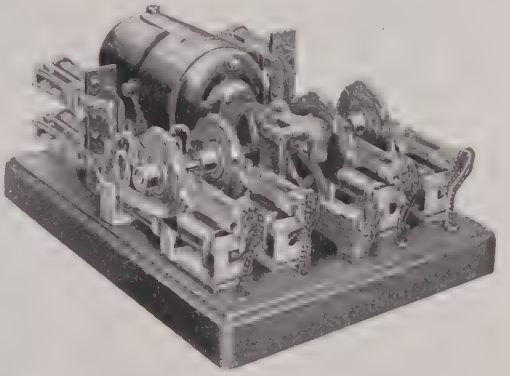


Fig. 5. Motor Key Equipment, Selector Type System

A 24-volt battery is located in the dispatcher's office for lighting the indicating lamps and for interlocking circuits in the equipment at that end. In addition, there is a 120-volt battery at each station for running the distributors and for furnishing the operating potential.

This type of system has demonstrated its reliability and practicability, and its maintenance and upkeep have been surprisingly low.

Cable Supervisory System

The cable supervisory system makes use of the same equipment as used in the distributor system with the exception of the distributors. In their place is substituted a multiple-conductor lead-covered cable. To control and indicate 50 breakers, 101 wires would be required between stations. Only one 120-volt battery is required if battery wires are run between stations. If the breakers are operated by alternating-current operating mechanisms, there would be no need of a battery in the substation.

Selector Supervisory System

The selector supervisory system uses standard selector equipment which has been employed successfully in train dispatching service for the past ten years. The dispatcher uses a control and indicating cabinet, Fig. 4, in which are inserted two operating keys and two indicating lamps, for each unit supervised. The control key is a spring-driven device which makes one revolution of a code wheel when the operating handle is turned through 90 deg. and released.

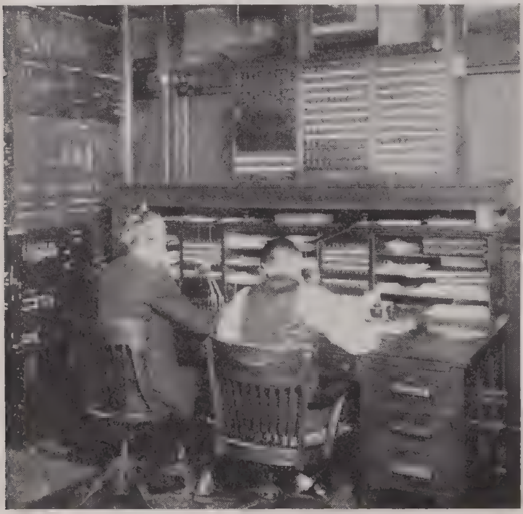


Fig. 6. Distributor Type Supervisory System in Use in the Load Dispatcher's Office of the Kansas City Power and Light Company

For each code sent from these keys, there is but one selector in the system which will step-up and close a contact. One key is used to close a breaker and the other to trip the breaker.

When a breaker in the substation operates, a motor-driven key sends impulses which are received on a selector relay in the dispatcher's office. This relay momentarily energizes an auxiliary relay which lights the correct indicating lamp corresponding to the position of the breaker.

The substation motor key, Fig. 5, is driven by a 24-volt, 1/50 h.p. direct-current motor. It has a capacity for sending in the open or closed position of four breakers.

In operating this system only one control key can be turned at a time, since the same line wires are used for sending coded impulses. In order to operate the selector relay, these impulses must be of alternate polarity, totalized to a definite value, and be equally spaced. It requires about seven seconds to send through a control operation and about the same length of time to receive the return indication from the substation. This makes the selector system much slower in operation than the distributor system when it is desired to operate several breakers at a time.

If several breakers open simultaneously in one or more stations due to overload, the return impulses to the dispatcher's office are so interlocked that there is no loss of signals. This is accomplished in the station by interlocks on the motor-driven sending key and between stations by the use of the third line wire.

Whenever an indication is being sent in from an outlying station a pilot lamp on the key and lamp cabinet is lighted. This notifies the dispatcher that he cannot send out a control operation. A bell also rings to call the attention of the dispatcher to any change in the supervised power equipment.

For the operation of this system, there is generally required in the dispatcher's office a small capacity battery of 144 volts. This battery is used for sending the coded impulses over the line wires. A small 24-volt battery is needed for the indicating lamps and the interlocking relays. In the substation, there is required a small capacity battery of 48 or 72 volts depending upon the distance to the dispatcher's office.

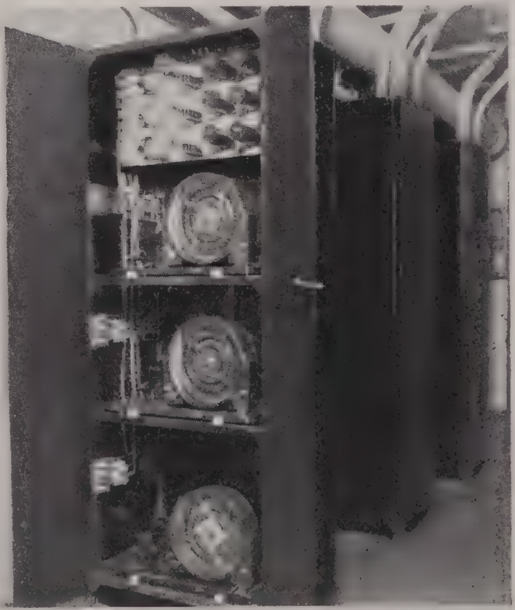


Fig. 7. Distributor Supervisory Cabinet, Showing Group of Distributors at the Dispatcher's Station

This equipment is particularly adapted for service similar to that found in interurban railway systems. There are but few operations which it is necessary to perform in any one automatic station supplying a railway load, and there may be a number of such stations along the right-of-way. It is generally desired to be able to start and stop, and have indication of whether the station is running or shut down. Usually, there are two or three feeder breakers per station over which it is desired to have supervision. The selector system will operate over three line wires interlinking all outlying stations with the dispatcher's office.

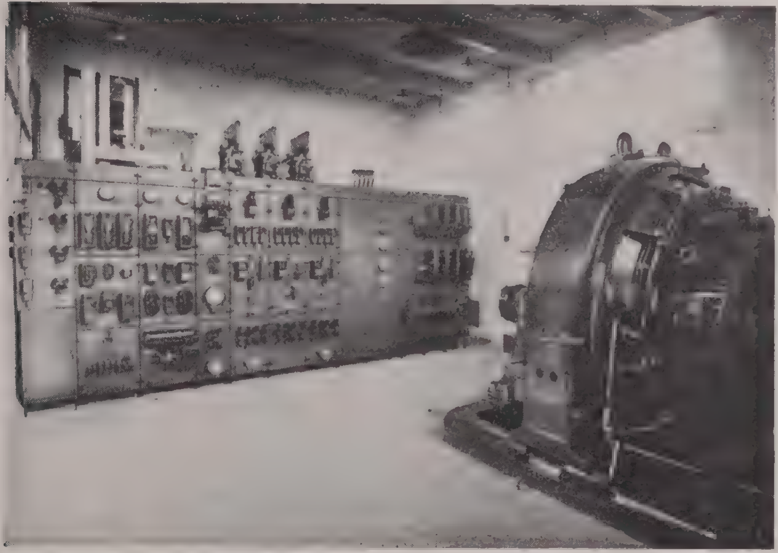


Fig. 8. 2000-kw. Synchronous Converter and Control Panels Completely Supervised by Selector Supervisory System; Chicago Rapid Transit Co., Central Street Station, Evanston, Ill.

Carrier-current Selector Supervisory System

The carrier-current system utilizes the same equipment as that employed in the selector supervisory system. The carrier equipment merely eliminates the necessity of three line wires between the dispatcher's office and the outlying stations. This feature in itself is quite important, for in many cases no additional line wires need be put up to apply the carrier-current supervisory system.

This system will operate successfully when coupled to an existing telephone circuit of open wire construction. The use of carrier current over this telephone circuit does not interfere with telephone communication. In cases where no open wire telephone circuit is installed, it is only necessary to put up a single insulated messenger circuit. Operation over the power transmission system itself is also possible in many instances. The feasibility of this arrangement depends upon the power circuits between the stations and the overall cost when applied to the higher voltage power lines.

The speed of operation is increased 100 per cent over that possible on the three-wire selector system.

Summary

It will be noticed in considering the foregoing systems that indication of all supervised equipment is made by red- and green-capped lamps at the dispatcher's office. When any change occurs in the system a bell and an indicating lamp call the attention of the dispatcher to that change.

It will also be noted that each of the systems finds a particular application in the supervision of electrical power equipment.

While the control and indication of oil circuit breakers only have been discussed in this article, these systems are readily adapted to the supervision of other types of units. As an example, the selector or the carrier-current system might be used to start or stop a hydro-electric station, raise or lower the load on any of the generating units, as well as control feeder breakers from that station. The dispatcher may be given an indication of the running or stopped condition of the generating units, the position of the gate opening, and the height of the water level in the forebay.

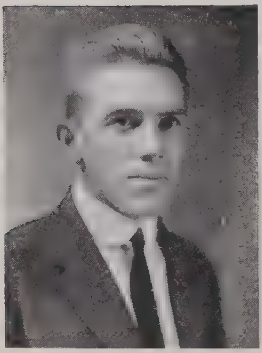
Whether these supervisory systems are used for controlling huge hydro-electric generating stations, eliminating running-light losses of transformers or rotating machines, or turning on and off street lights of our modern cities, they are of untold benefit to electrical operating companies.

Automatic Stations; Here, There, and Everywhere

Fascinating Performance of the Automatic Station—Its Exceptional Versatility of Location and Service—Deep in Mines—Along Interurban Railway Lines—In Residential Districts—At Waterpower Developments—Map and Table of Number and Location

By H. W. Ewald

Automatic Station Division, Switchboard Department, General Electric Company



H. W. Ewald

THE automatic station, like radio telephony, is truly one of the marvels of the present age. Only a few years ago one remembers the thrill and feeling of awe experienced when hearing for the first time the human voice coming through the air from a great distance. It reminded the layman of an "Arabian Nights' Tale" made into a reality as there seemed to be magic in the little box from which the sounds came. A similar feeling of the supernatural occurs when one first visits an automatic station.

A few years ago on a hot summer day when making some adjustments in an automatic electric railway substation situated in a lonely spot, a severe thunderstorm came up suddenly. A lightning disturbance interrupted the high-tension alternating-current power about 30 miles away which in turn caused the immediate shut down of the two large converters in the substation and thus interrupted the trolley service. As soon as the rain subsided a little, several Italian track workers came rushing into the station. Their day's work was over and they were anxious to get a trolley for home. The first thing they noticed was the silent converters and were greatly concerned because no visible attempt was being made to start them. Their impatience increased as time wore on and it could be readily discerned from their gestures and excited foreign tongues that the apparent lack of interest in starting the machines was the whole cause of their delay in getting home to supper. But suddenly all was changed, the high-tension alternating-current power returned, and quick as a flash the contactors in various parts of the station started to bang in, relays clicked amid the whizzing noise of first one converter and then the other as they came up to speed and were connected to the trolley system; all in a period of seconds. The whole station was again alive and seemed to be under the control of many invisible hands. The track workers were dumbfounded with amazement.

The automatic station like other mechanical inventions to save labor not only conserves human energy but performs certain duties much better than a man because of his limitations. For instance, it is impossible for an operator to tell if there is a short-circuit on a feeder, and he closes the breaker that connects the feeder to the power source hoping that all is well, but if a short-circuit exists the breaker immediately trips. He then waits a while before trying it again. This process is generally repeated several times before the operator is sure the feeder is permanently short-circuited and requires an inspection. But with the automatic reclosing feeder system a clever relay senses the condition of the feeder and will not direct the closing of the breaker as long as the feeder is in trouble. A bearing on a machine in a manual station may become overheated quickly and scored sufficiently to require repairs even if the operator is nearby paying strict attention to his work. But in an automatic station a temperature relay senses the trouble when the bearing reaches the temperature of boiling water and instantly shuts down the machine for inspection.

It is natural that this superior type of station has had a remarkable growth since its beginning about ten years ago, and we find them scattered over our whole country and many in foreign lands. They are in the most congested city areas, residential sections, lonely mountain spots, and even in mines deep in the earth; in fact wherever the wheels of industry are turning. The map on pages 456 and 457 shows the widespread use in the United States of automatic stations which were manufactured by the General Electric Company. A different symbol is used for each main class of equipment and the figure next to the symbol denotes the number at the given spot.

A more detailed consideration of a few of these stations that in some way are unique will give a better idea of the versatility of the automatic station.

To visit the substation shown in Fig. 1, it is necessary to decend into the ground about 350 ft. in a mine shaft of the Mount Olive and Staunton Coal Co., at Staunton, Ill. Near the bottom of the shaft is an electric shop containing a control panel in a small booth about 4 ft. by 5 ft. From this booth the chief electrician supervises this motor-generator station as well as three other similar ones. The nearest is about a half mile away and the farthest is about a mile and a half. They are located in little rooms cut out of the main entries. If any one of the stations shuts down when not directed to do so by the chief electrician, an alarm bell rings to notify him that an inspection is required before it will start again. The chief electrician can also tell the load carried by each station and can thus start and stop them as required.

Another interesting automatic motor-generator installation is located at the Wolf Pit Mines of the McKinney Steel Company, Wolf Pit, Kentucky. There are two motor-generator sets in this station which are completely automatic except that they receive their starting and stopping impulses from a distant station by means of a relay connected to supervisory control apparatus. By using a certain code number the station is started. A second number enables the supervisor to listen to the operation of the machine. A third number shuts down the machine. The second unit of this station automatically starts and connects itself to the direct-current bus if the first unit fails to to go through the proper starting sequence, becomes overloaded, or shuts down because of some trouble such as a hot bearing, overheated machine windings, etc.

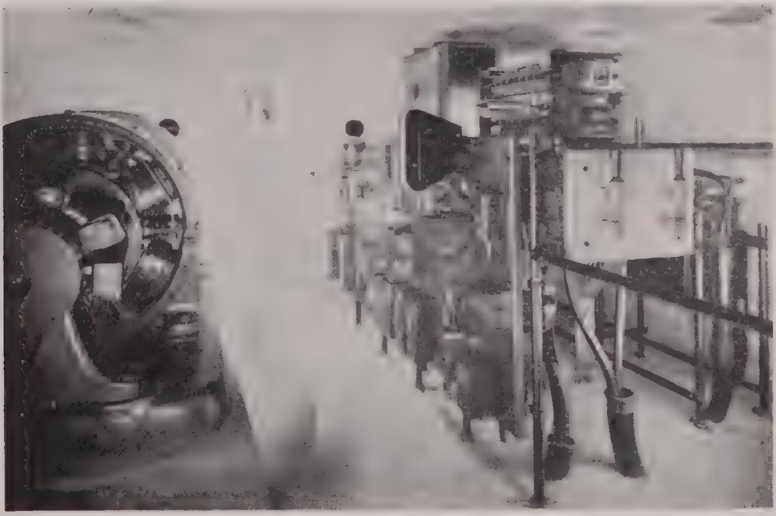
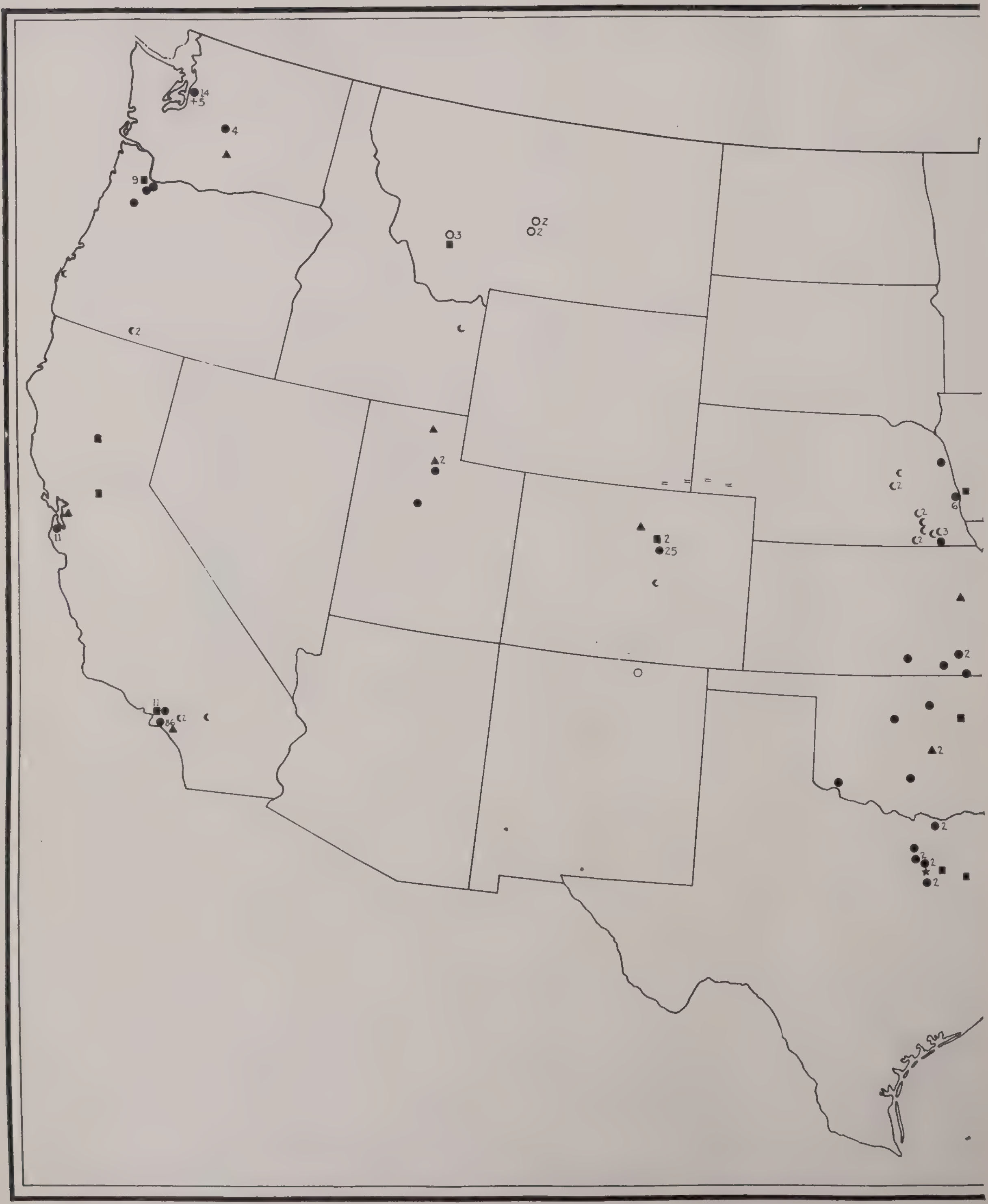
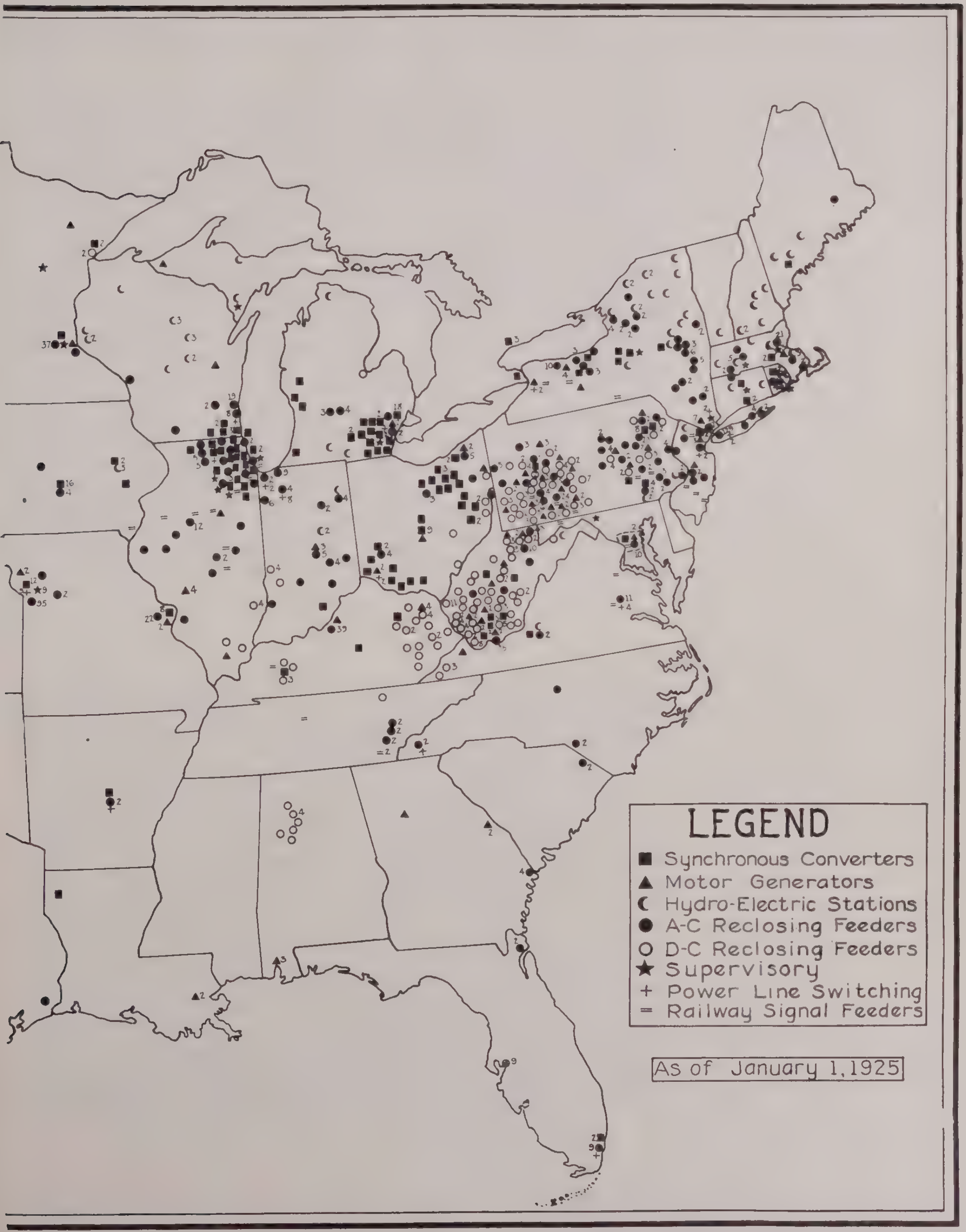


Fig. 1. Installation 350 Feet Underground in a Room Cut Out of the Main Entry of a Coal Mine

At the Dorrance Colliery of the Lehigh Valley Coal Co., there is a motor-generator set 600 ft. below the surface, which is automatically controlled and feeds power to a trolley system at this level. Another set, 1100 ft. below the mine mouth, is also automatically controlled. The 2300-volt, 60-cycle supply to each of the motors is controlled from the surface substation, and the control of the direct-current power from each generator is located near the set. The control scheme is so interconnected that either machine may be started or stopped from three points by a knife switch on the switchboard, by a push button at the mouth of the mine, or by another push button beside the set. The machines may also be locked out



LOCATION OF 1873 AUTOMATIC EQUIPMENTS



IN SERVICE IN THE UNITED STATES

of service from any of these points. These equipments were installed in the spring of 1922. The set on the 1100-ft. level is the deepest automatic station in a coal mine.

The station exposed to the worst atmospheric conditions is in a salt mine 1100 ft. underground at Retsof, New York, the property of the Retsof Mining Co. The equipment was given special treatment to render it rust resisting. The station has operated successfully for several years in spite of the fact that the relays, contactors, and other devices are covered with a heavy salt deposit. This is probably the only automatic station in existence where the equipment is suspended from the roof of the mine rather than resting on the floor. The reason for this peculiar installation arrangement is the unstable condition of the mine floor.

Deep snow drifts that almost envelop stations in exposed areas are not a very serious cause of worry to the owner of an automatic station. The Drifton automatic station of the Lehigh Valley Coal Company was snowed in so badly a few years ago that it was not visited for five days. But the output of coal from the mine, whose only source of power is this station, was not affected by this mishap for the automatic equipment faithfully performed its duty.

The electric railway automatic substation is especially interesting. A whole chain of these stations are used to carry the electric trains along their journey. The automatic station starts as the train approaches and supplies current to it while traversing the substation zone; the station then shuts down and awaits the approach of another train. In the meantime the station next in line starts and furnishes power to the oncoming train. The train thus always draws its power from nearby power sources with all its resultant advantages.

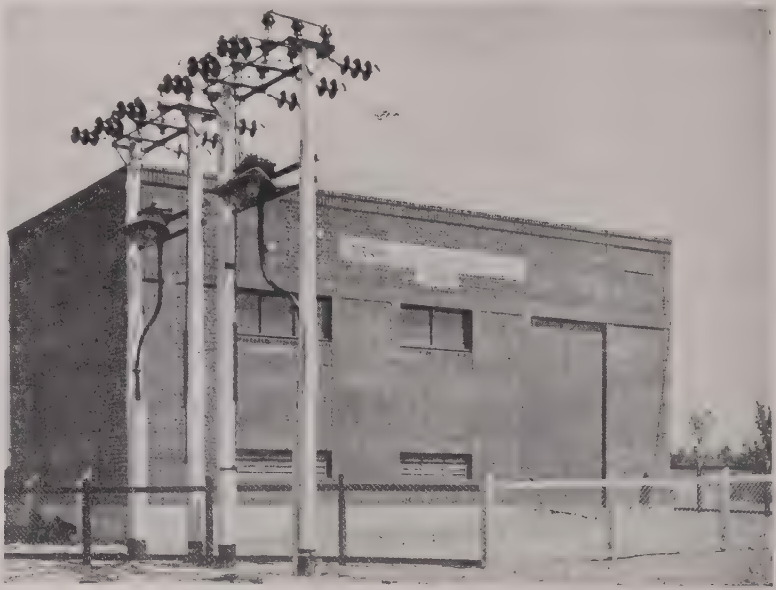


Fig. 2. First Completely Automatic Railway Substation in Australia

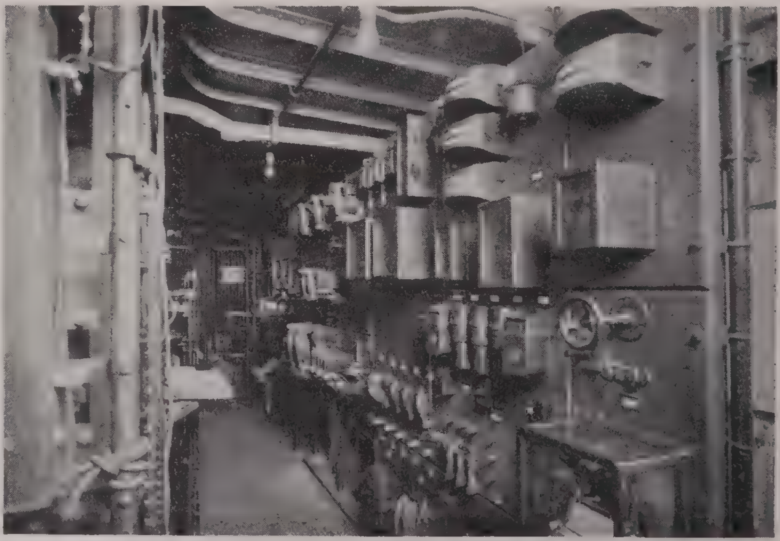


Fig. 3. A Railway Car is the Home of this Portable Installation

Australia has the distinction of being the first country outside of the United States to install a non-attendant substation. This was a remotely controlled railway substation equipped by the General Electric Company and installed by the New South Wales Government Railways. It was followed by several similarly controlled substations on the same system. The first completely automatic substation in Australia, Fig. 2, is the property of the Perth Tramway Company.

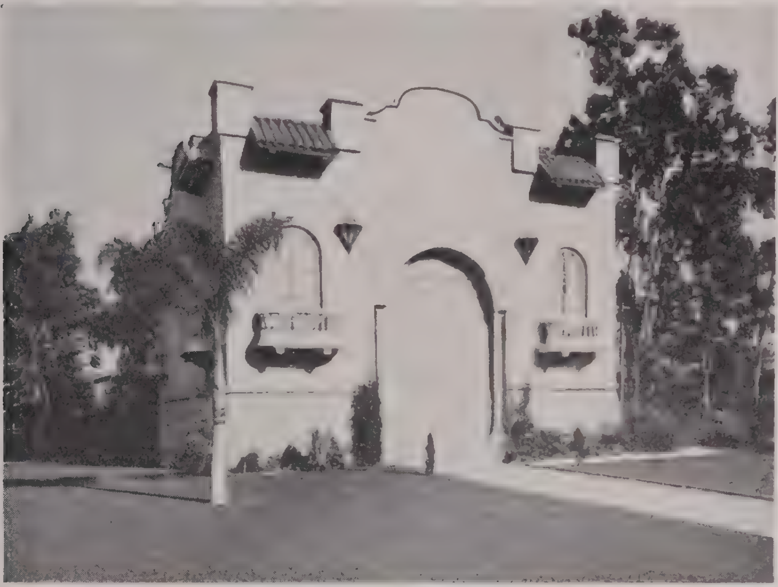


Fig. 4. Noiseless Automatic Railway Substation in a Beautiful Residential Section of Los Angeles

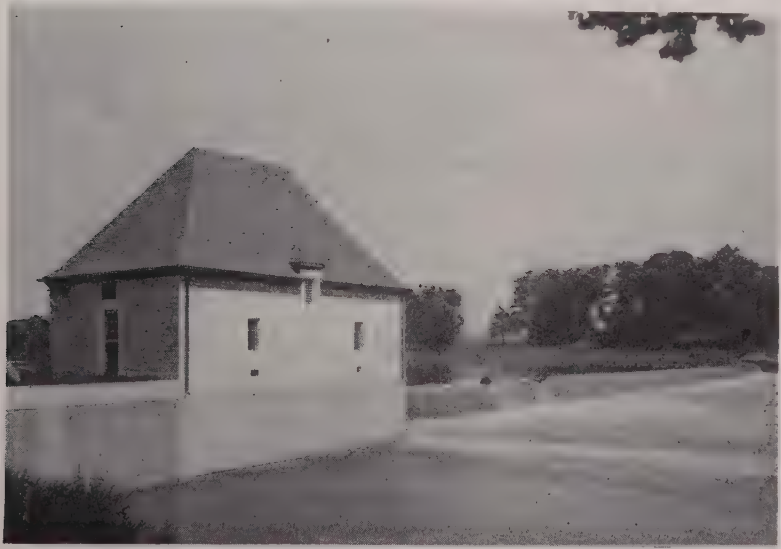


Fig. 5. An Automatic Hydrolectric Station in a Lonely Place

City trolley systems are often handicapped by not being able to place their power apparatus at load centers when they fall in exclusive residential areas, because people dislike the noise and other objectionable features of manual substations. This problem is very easily solved by the use of an automatic substation such as shown in Fig. 4. The station is noiseless due to its soundproof construction and its architecture corresponds to the other buildings in the neighborhood. Special blower motors are used to force air through the station to keep the machines and other equipment cool.

There are also automatic substations on wheels. Portable equipments are used by many electric railway companies. Whenever an unusually heavy load exists temporarily at any point on the line or when any substation develops serious trouble, it is only necessary to rush the portable unit to the needed spot, connect the alternating-current and direct-current lines and then throw a small switch which places the automatic equipment in operation and restores the service. A typical equipment of this sort is shown in Fig. 3.

It may seem like a far cry from the city substation to the lonely scene where huge waterwheels are converting the energy of a stream into electric power. But here too the automatic station is in charge, for the isolated location of most waterwheel stations makes automatic equipment of special value. The station in Fig. 5 is a typical installation of this kind.

TABLE I

AUTOMATIC EQUIPMENTS—JUNE 1, 1925

Classification	Total Number	Total Kw.	Average Kw.	LARGEST EQUIPMENT		SMALLEST EQUIPMENT	
				Rating	Location	Rating	Location
MACHINES							
Synchronous Converters for Railway Service........	237	169,700	715	2500 kw.	New York Central R.R.	200 kw.	The Connecticut Co. and others
Motor-Generators for Railway Service...........	54	75,000	1390	3000 kw.	Georgia Railway & Power Co.	200 kw.	St. Joseph Ry. Lt. Ht. & Pr. Co.
Hydro-electric Generators..	117	122,270	1045	9375 kv-a.	Northern N.Y. Utilities Co.	50 kv-a.	Romney Power Co.
Synchronous Converters for Lighting Service........	20	36,910	1846	3700 kw.	Cleveland Elec. Illum. Co.	500 kw.	Detroit Edison Co.
Motor-Generators for Lighting Service............	32	41,695	1300	2100 kw.	N. Y. Edison Co.	25 kw.	Oklahoma General Power Co.
Synchronous Converters for Industrial Service.......	29	8,780	300	500 kw.	Appalachian Power Co. and Royal Dutch Blast Furnace	150 kw.	Southern Mining Co. and others
Motor-Generators for Industrial Service........	75	19,825	265	500 kw.	Appalachian Power Co. and Laclede Steel Co.	150 kw.	Cochran Coal Co and others
Synchronous Condensers..	5	19,000	3800	5000 kv-a.	American Steel and Wire Co.	500 kv-a.	Indiana and Michigan Electric Co.
Total Machines......	569	493,180	870				
FEEDERS AND OTHER CLASSES							
A-C. Feeders...........	1425	1,422.400	1000	2340 kv-a.	Utah Power & Light Co.	14.5 kv-a.	Long Island Lighting Co.
D-C. Feeders Industrial..	314	83,880	270	1100 kw.	Berwind White Coal Mining Co.	41.25 kw.	Engels Copper Mining Co.
Railway Signal Feeders...	56	921	16	100 kw.	Delaware, Lackawanna & Western R.R.	0.357 kw.	Louisville & Nashville Ry.
Supervisory Equipment...	*53	....	....	†	Public Service Production Co. of New Jersey	‡	Northern States Power Co.
Power Line Switching.....	42	217,346	5180	7500 kv-a.	Kansas City Power & Lt. Co.	20 kv-a.	Puget Sound Pr. & Lt. Co.
Total Feeders, etc....	1890	1,724,547					
Grand Total Equipments..	2459	2,217,727					

* These 53 supervisory equipments control 486 units (oil circuit breakers, machines, etc.) and indicate the position of 1875 units.

† Position of 670 units indicated and 114 units controlled.

‡ Position of 2 units indicated and 2 units controlled.

The first automatic hydro-electric station in Japan was installed by the Kyushu Electric Light and Traction Company in 1923. This station created so much interest that the superintendent had to set aside visiting hours to accommodate those who were merely curious as well as those who were actually interested in the functioning of the equipment.

The smallest automatic hydro-electric station is one of 50 kv-a., located at Romney, W. Va. The largest one contains two hydro-electric generators each of which is nearly 200 times the power rating of the one at Romney. This latter is the Soft Maples Falls Station of the Northern New York Utilities Company. Each of the generators is rated at 9375 kv-a. The automatic equipment for these two units is shown in Fig. 6. This is a factory view of the equipment taken just before its preparation for shipment.

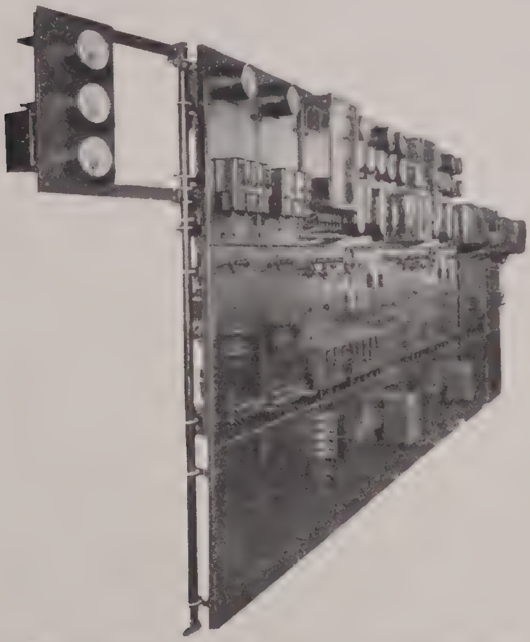


Fig. 6. Switching Equipment for the Largest Automatic Hydro-electric Station in the World

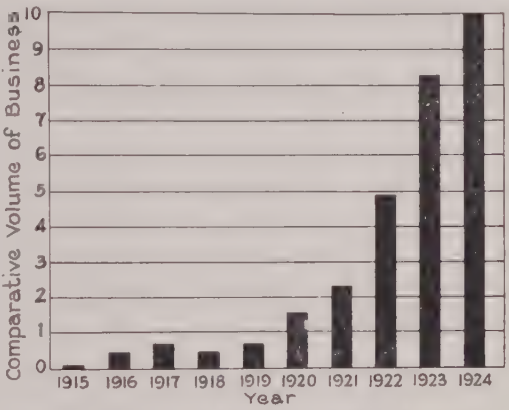


Fig. 7. Growth of the Automatic Switching Equipment Business During the Past Ten Years

Summary of Automatic Station Installations

In 1914 the first completely automatic station was put into operation at Union, Ill. Up to June 1, 1925, a little more than a decade later, 2459 General Electric equipments controlling nearly two and a quarter million kilowatts of power had been purchased. Table I shows for each class the total number of General Electric equipments, the total capacity, the average size of equipment, and the largest and smallest.

Of these equipments, 117 are in foreign countries and have a combined capacity of about 82,000 kw.

Fig. 7 shows the growth of the automatic station business during the past ten years. The dip from 1917 to 1919 was caused by the World War. Since 1919 the business has increased very rapidly; the value for 1924 being about 15 times that of 1919.

In laying out the operating program of a completely automatic switching equipment, the designer does not have to make allowances for the human limitations of an operator

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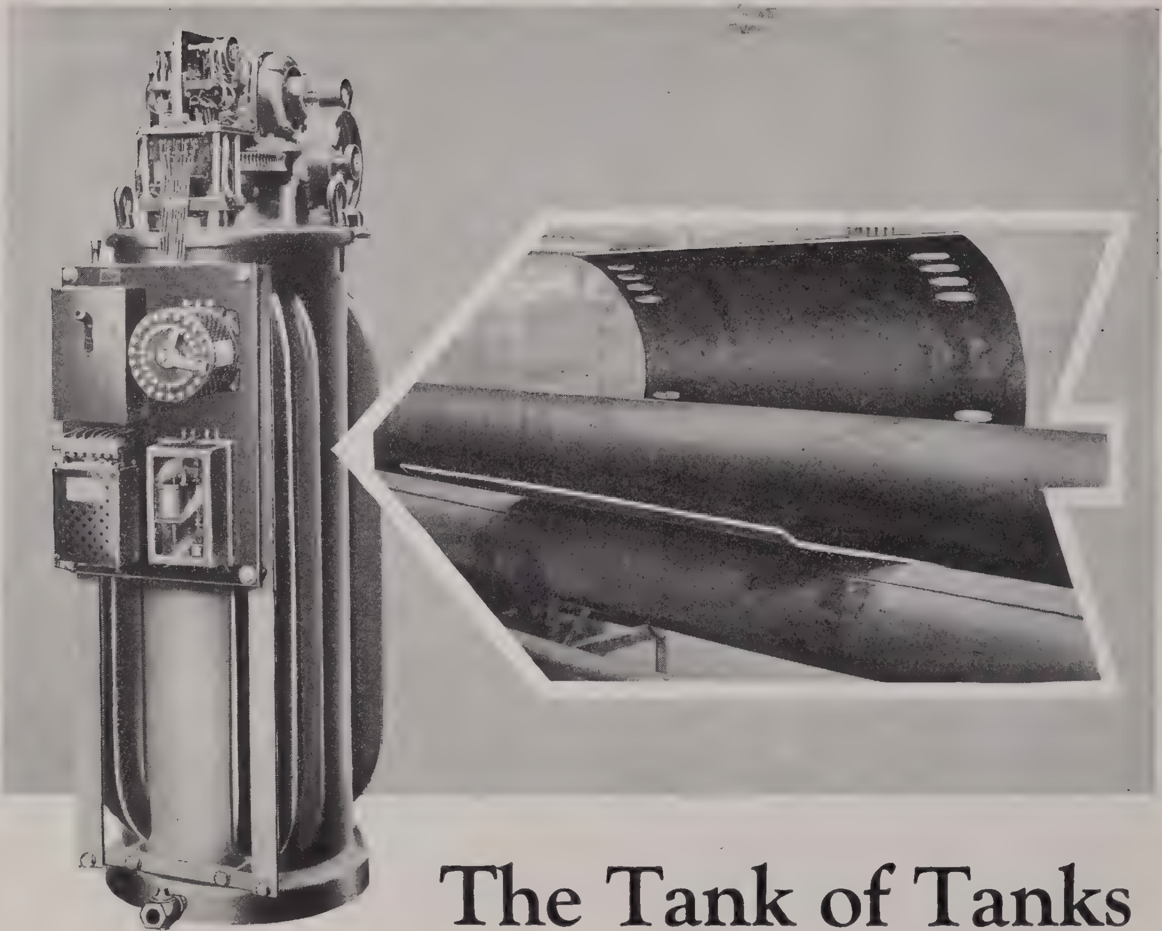

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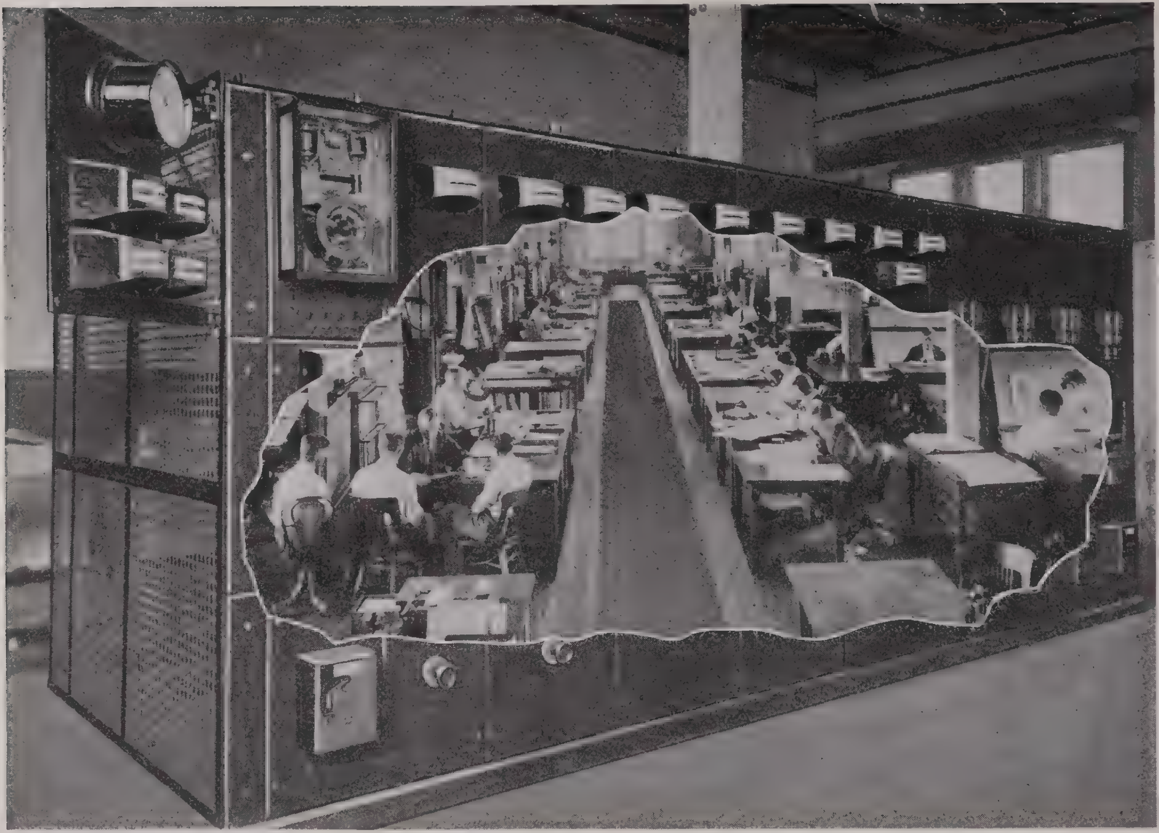

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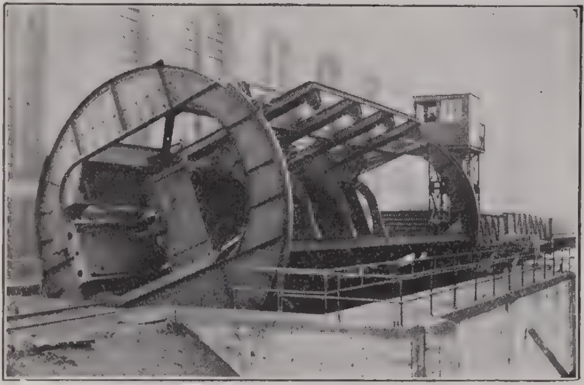

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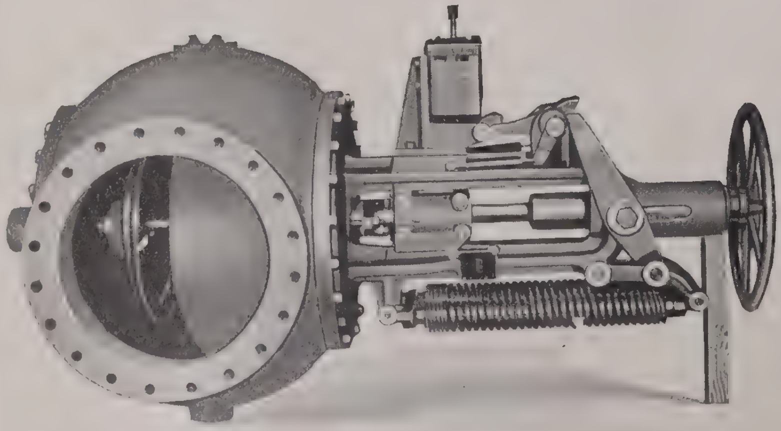

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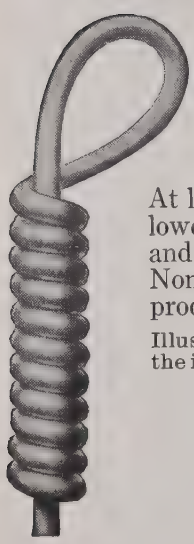

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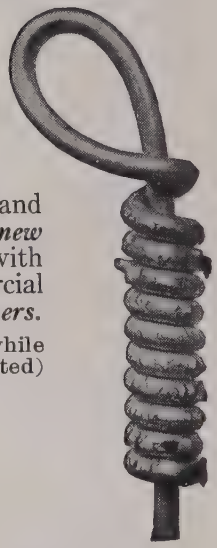
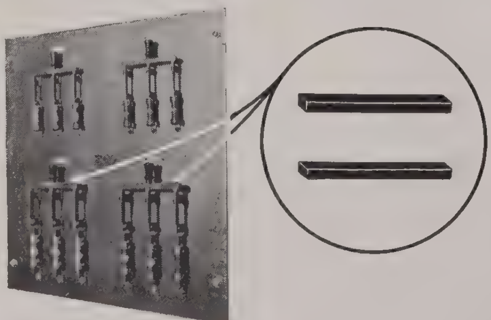


Galvanized Steel Strand

Standard or Commercial, Siemens-Martin, High Strength and Extra High Strength Grades

Indiana Steel & Wire Company, - - Muncie, Indiana

One of its many electrical uses



Insulating Plates for Gutter Boxes on House Circuits

—is a use of SPAULDING HARD FIBRE that illustrates its low cost, electrical resistance and mechanical strength.

It will not sag nor deteriorate from the weight of instruments mounted on it. It improves, rather than deteriorates with age, making it the ideal insulator for numerous other electrical purposes.

Cuts the cost of insulation

Samples and prices on request

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Branches: New York City, Boston, Chicago, Philadelphia, San Francisco, Los Angeles, Detroit, Cleveland

SPAULDING Fibre COMPANY

Spaulding HARD FIBRE

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IN building motors, generators, transformers, switchboards, trolley controls, electric elevator controls—wherever step control is used, Diamond Fibre is especially needed.

Diamond Fibre insulation has a dielectric strength of 200 to 400 volts per mil of thickness. It is dense and homogeneous. It can be sawed, punched, threaded, and turned. It does not break or crack under extreme twisting and bending.

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Our Engineering and Laboratory Department will gladly send you further information on request.

Diamond State Fibre Co.

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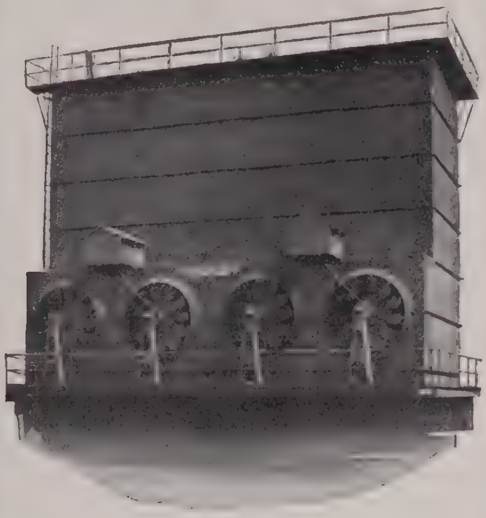
The oldest and largest manufacturer of vulcanized hard fibre and laminated technical materials in the world.



Cool Condenser Water on Hot, Humid Days

And on all other days this C. H. Wheeler Forced Draft Cooling Tower, re-cools the circulating water, resulting in a high vacuum being carried the year around.

Where space is available a Natural Draft Cooling Tower may be installed.

Let us solve your condenser water re-cooling problem.

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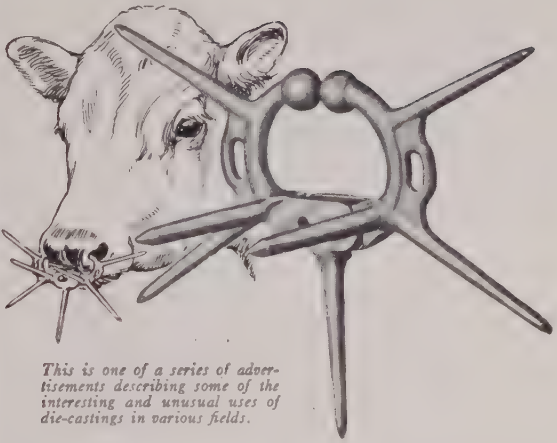
"C. H. Wheeler of Philadelphia"



This is one of a series of advertisements describing some of the interesting and unusual uses of die-castings in various fields.

An odd-shaped die-casting with an equally odd use

THIS strange-looking device is known to dairymen as a "weaner."

Clamped on the nose of a calf, the weaner accomplishes what its name indicates by convincing the mother cow that it is less irritating to keep her hungry offspring always at a distance. One prod of the prongs is usually sufficient to carry conviction.

The weaner is typical of some of the unusual jobs which we, as manufacturers of aluminum, zinc, lead and tin die-castings, are called upon to turn out. If a device or a machine part can be die-cast, we can make it. Unusual, intricate die-casting problems are our forte. Moreover, our large manufacturing facilities enable us to produce die-castings of any type, in any quantity, economically and expeditiously.

Your inquiries, accompanied if possible by a blueprint or a model, are solicited.

When you buy die-castings from us, you are assured of the same high quality that has established our Dutch Boy trademark as a mark of excellence on babbitts, solder and paint materials.

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"Megger" Testing Sets

are the accepted standard among engineers for insulation resistance tests of generators, motors, transformers, insulators, cables, wiring and other electrical apparatus, at installation and for general maintenance.

Instruments are available which read directly as low as 5 ohms and as high as 10,000 megohms.

Catalog 1075-G contains valuable, up-to-date data on insulation testing. **Write for copy.**

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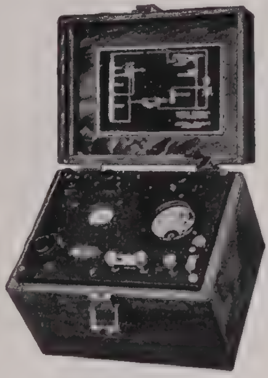

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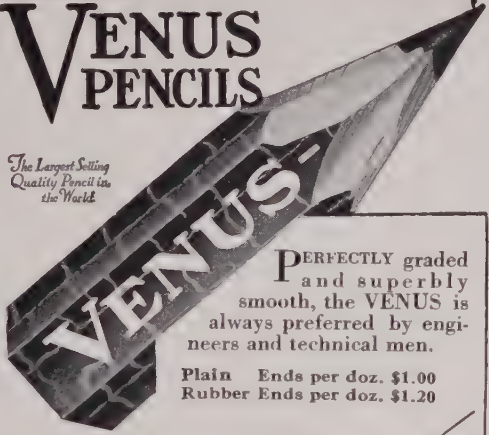

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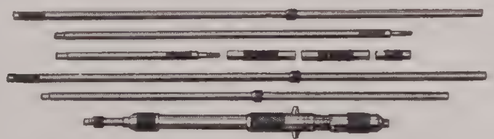

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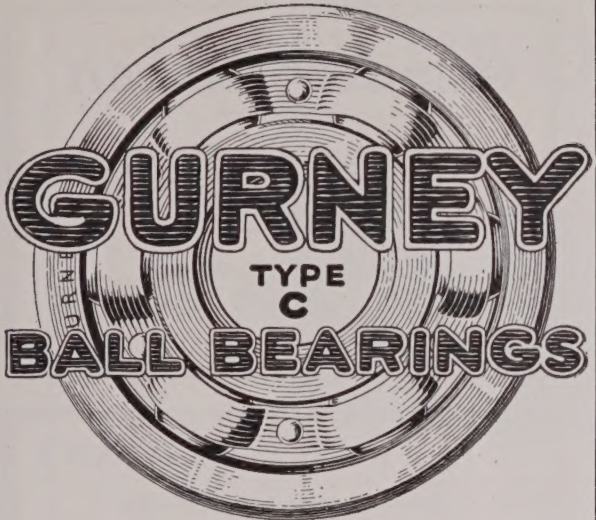

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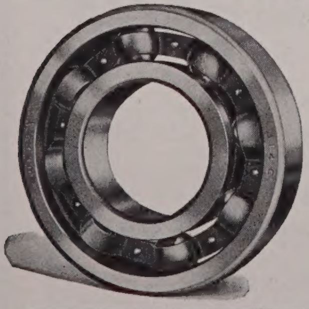

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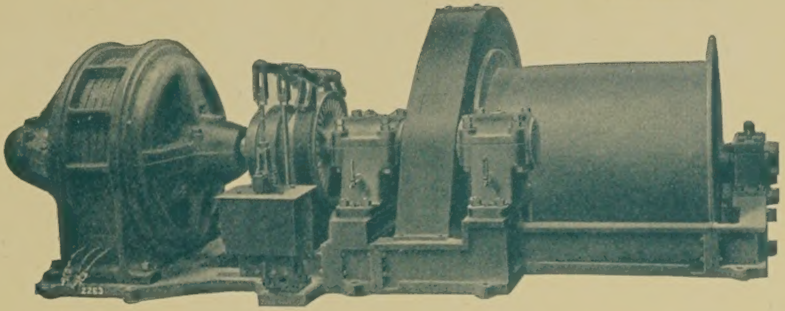

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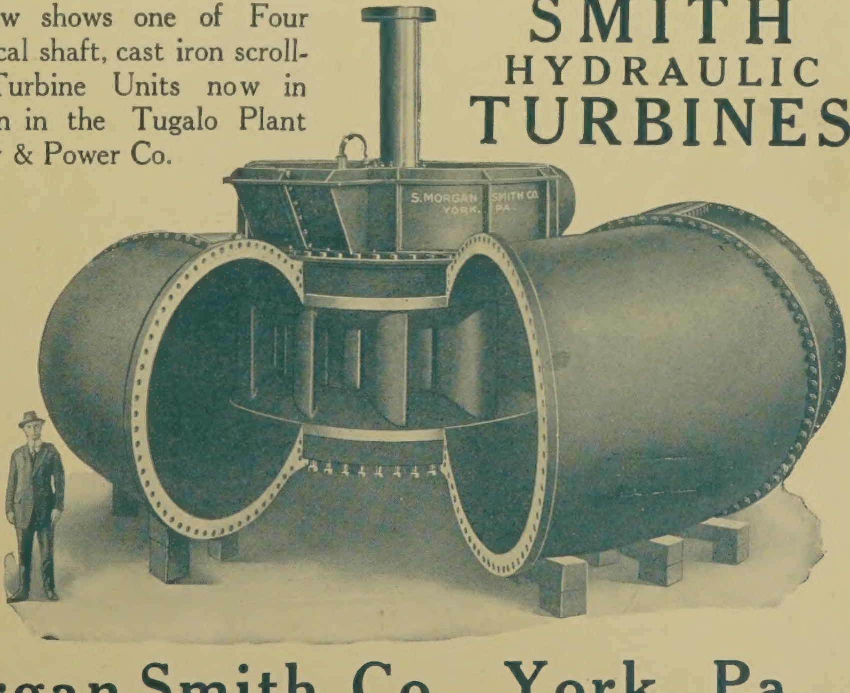

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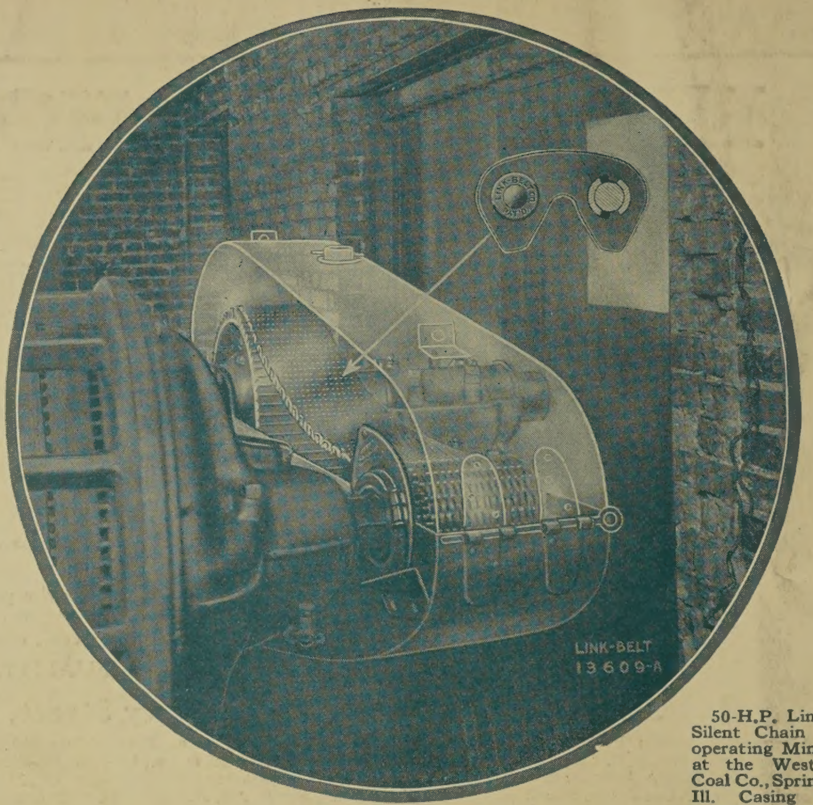

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